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Structural Restraints and Flange Stud Integrity – Safety Critical Issues for Under Pressure Leak Sealing

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Structural Restraints and Flange Stud Integrity – Safety Critical Issues for Under Pressure Leak Sealing

The most likely causes of a serious incident when performing Under Pressure Leak Sealing are:

- **Total circumferential failure of the pipe inside an enclosure clamp.**
  - Leading to separation of the two parts of the pipe.
- **Failure of flange studs when injecting a flange.**
  - Leading to separation of the flanges.

Either of these incidents can cause a sudden and catastrophic release of the pressurised product

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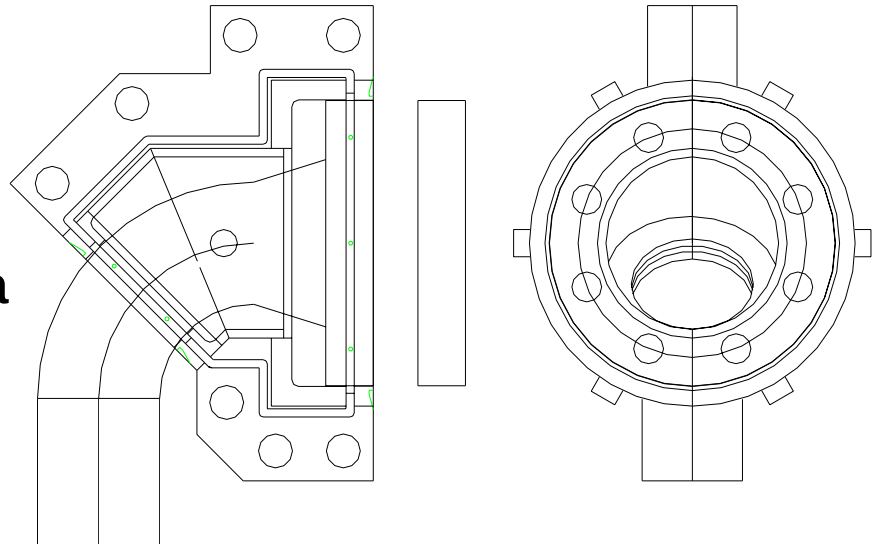
Pipe Failure Inside Enclosure Clamp Incident 1

- Clamp installed over flange and part of an elbow on an offshore oil platform.
- DN 75 (3 inch nb.) pipe carrying NLG at 60 bar.
- Pipe was not leaking but significant wall thinning at a weld had been detected by NDT.
- Clamp was sealed at the periphery (injected seal grooves), but also filled with hard setting epoxy resin.



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Pipe Failure Inside Enclosure Clamp - Incident 1

- Clamp Installed in January 1997
- May 1998 – weld failed – elbow and clamp parted from flange. Hydrocarbon release at approx. 60 bar. Platform shut down. No injuries.

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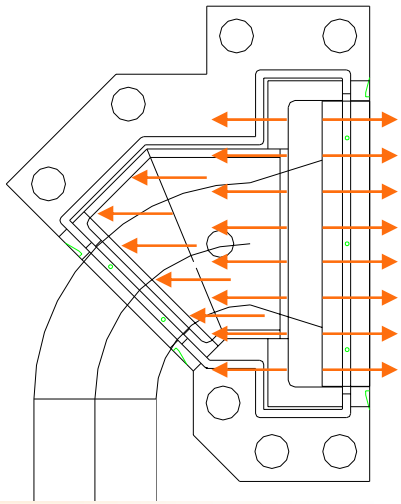
Pipe Failure Inside Enclosure Clamp - Incident 1

Incident Analysis



- **The clamp was subject to out-of-balance forces (differing bore sizes).**
- **No restraint was provided – it was assumed that the clamp could not move because of the elbow configuration and the resin fill.**
- **If the clamp void becomes pressurised (due to a through wall defect and leakage under the resin fill), clamp restraint loads are passed through the defective weld.**
- **The presence of clamp may have caused the pipe to failure earlier than it otherwise would have.**

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Pipe Failure Inside Enclosure Clamp - Incident 1

Incident Corrective Actions

- **Must assume that resin filled cavities will pressurise to full line pressure.**
- **Must ensure that all clamps subject to out of balance loads are adequately restrained**
- **Must ensure that such restraint is provided in a manner which does not place unacceptable additional loads on piping components (especially defective ones).**
- **Must ensure that clamps whose geometry is such that pressurisation of the void might impose additional loads on the enclosed piping, are provided with suitable means for carrying the additional loads through the clamp.**

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Pipe Failure Inside Enclosure Clamp Incident 2

- Clamp installed over DN 150 (6 inch nb.) by DN 75 (3 inch nb.) reducer.
- Pipe was carrying boiler feed water at 100 bar and 110°C.
- Pipe was leaking through a “pin hole” just downstream of the weld at the DN 75 (3 inch nb.) end.
- Clamp was sealed at the periphery (injected seal grooves), and was fitted with a restraint at the DN 150 (6 inch nb.) end to anchor the clamp against the pressure thrust resulting from the differential bore diameters.
- Clamp was installed in July 2000 and re-injected the following December and March.

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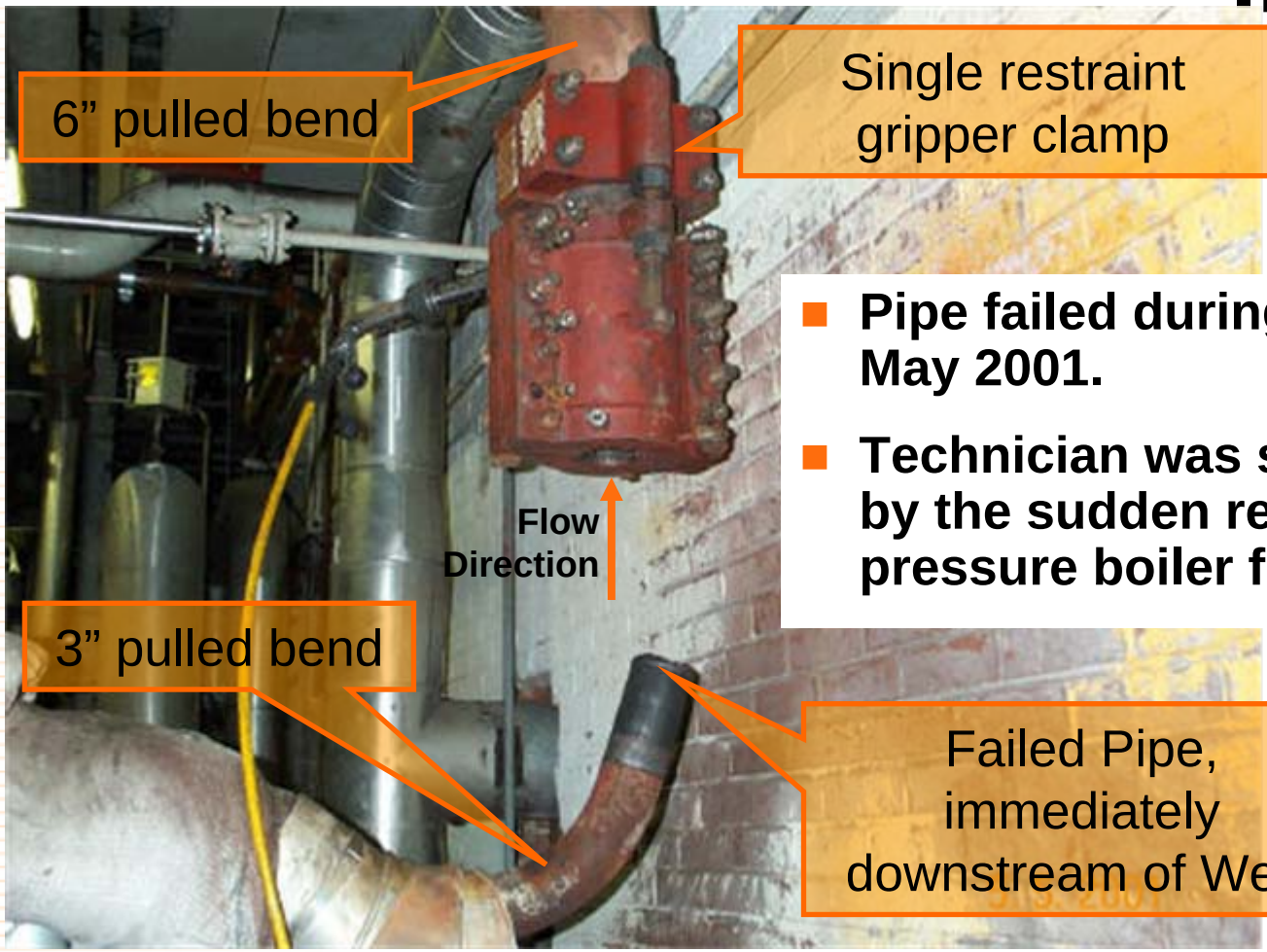
Pipe Failure Inside Enclosure Clamp Incident 2



- **Pipe failed during 3rd re-injection, May 2001.**
- **Technician was severely scalded by the sudden release of hot, high pressure boiler feed water**

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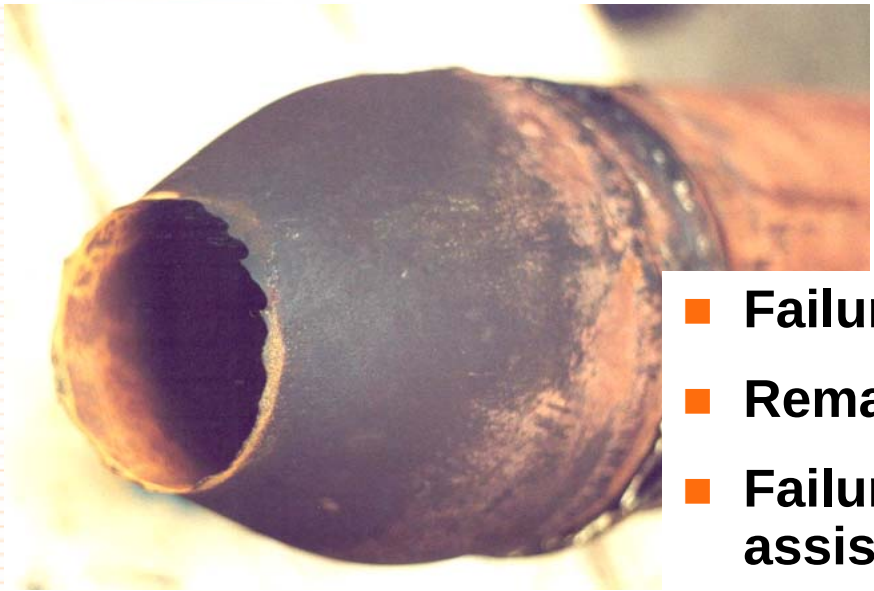
Pipe Failure Inside Enclosure Clamp Incident 2



- Failure immediately downstream of weld.
- Remaining wall thickness <<1mm.
- Failure mechanism identified as erosion assisted corrosion.
- Defect probably originated by a recessed or proud root run in the weld.
- Pipe had been in service approximately 20 years before pin hole appeared

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Pipe Failure Inside Enclosure Clamp - Incident 2

Incident Analysis

- **Root cause of the accident was the failure (by both the customer and contractor), to appreciate the potential extent of the defect.**
  - Pin hole leaks in 20 year old plant are commonly the first visible indicator of a much more substantial internal defect.
- **The clamp should have been fitted with another restraint at the DN 75 (3 inch nb.) end.**
- **Then existing policy for the need for restraints was clearly inadequate.**
  - Policy was that the customer made that decision based on their knowledge of their plant, its history, service experience, likely degradation mechanisms, expected corrosion rates, etc.

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What are Structural Enclosure Clamps?

- All enclosure clamps are designed to fit around a defective (usually leaking) pipe or piping component and contain the pressurised pipeline fluid.
- Additionally, a ***structural*** enclosure clamp must provide a means of carrying the axial pressure load from one side of the defect to the other, in the event of complete pipe severance.
- A non-structural enclosure clamp provides containment of the leaking fluids only.

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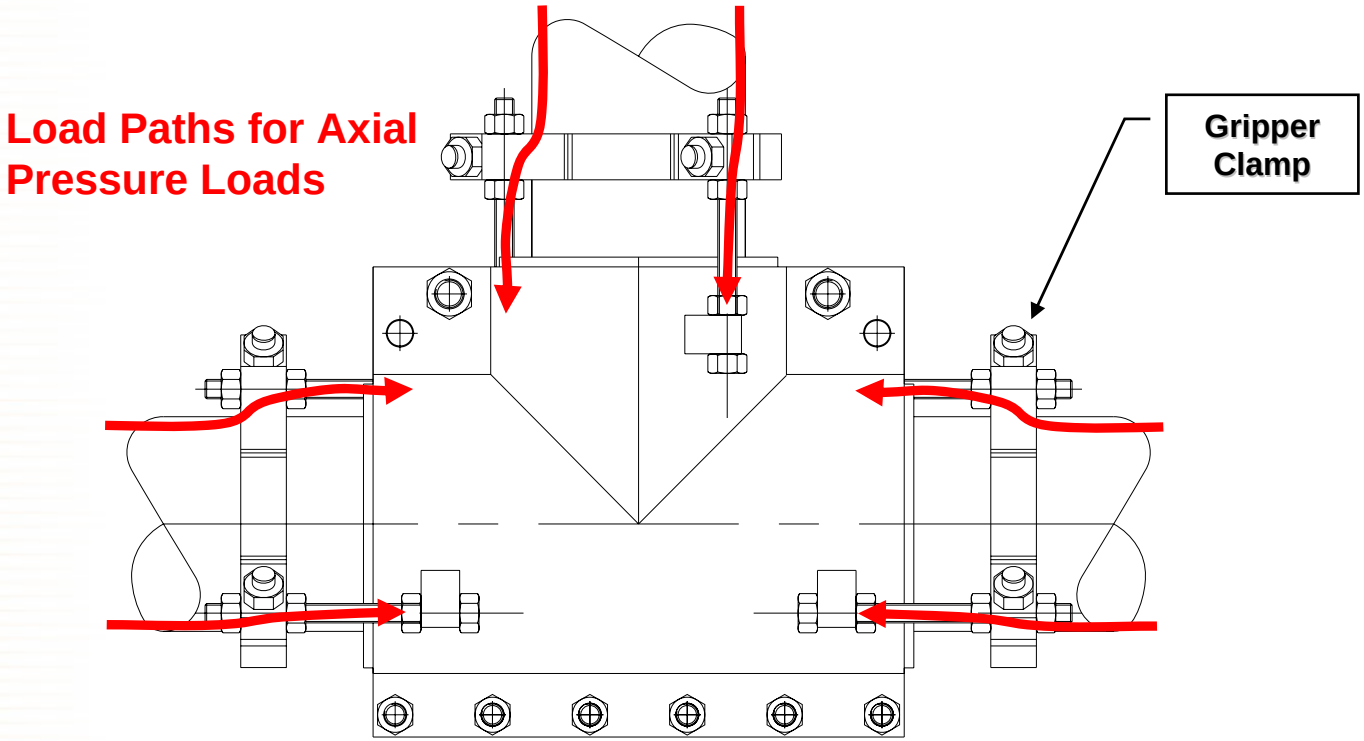
What are Structural Enclosure Clamps?



Structural Enclosure Clamp Example with Full Axial Restraint

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Why Would a *Structural* Enclosure Clamp be Required?

- **For some defects, enclosing the defect will prevent further deterioration of the pipe.**
  - For example - external corrosion.
- **For other defects, the pipe may be expected to continue to deteriorate inside the enclosure.**
  - For example - internal corrosion / erosion.

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Why Would a *Structural* Enclosure Clamp be Required?

- **If the pipe might deteriorate to the point where it can no longer support the axial stresses in the pipe, then a *structural* enclosure clamp is required.**
  - A structural clamp provides an alternative load path for the axial loads - around the defect.
- **If a non-structural clamp is used in such circumstances, then complete pipe separation can occur, leading to the sudden release of pipeline fluids at full pressure.**
  - If this happens, there is a high risk of serious injury, or worse…
- **Such incidents are rare, but they do occur and the consequences have been extremely serious.**

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Policy On The Provision Of Structural Enclosure Clamps

- **Previous policy left the onus on the customer to determine whether or not a structural clamp was required.**
- **Under a revised policy, Furmanite will assess the requirement for structural clamps, based on a risk assessment of each job.**

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Policy On The Provision Of Structural Enclosure Clamps

Basis of Policy:

- **All Clamps will be structural (fitted with axial restraints) unless they satisfy one or more exemption criteria.**

Policy On The Provision Of Structural Enclosure Clamps

***Exemption Criteria**: Non-Structural Clamps (with no axial restraints) may be permitted by reason of:*

- **The defect nature and location.**
  - The likelihood of failure.
- **Operation conditions (Pressure, temperature, pipe size and contents).**
  - The consequences of failure.

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Policy On The Provision Of Structural Enclosure Clamps

Exemption Criteria - Defect Nature And Location

Exemption applies where the defect is due to:

- **External corrosion.**
- **Internal corrosion / erosion on the extrados of an elbow / bend, or opposite the branch of a tee - subject to 12 month limit on the service life for the clamp.**

Or where:

- **The defect is such that a piping component is intrinsically restrained by the clamp - subject to 12 month limit on service life and 20 barg limit.**

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Policy On The Provision Of Structural Enclosure Clamps

Exemption Criteria - Defect Nature And Location (….continued)

Exemption applies where:

- **The nature and location of the defect can be shown to be such that the long term structural integrity of the pipe is not compromised.**
  - This is a special case and requires written evidence (for example NDT reports) and authorisation by a Furmanite Mechanical Engineer.

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Policy On The Provision Of Structural Enclosure Clamps

Exemption Criteria - Operating Conditions:

- **Fluids will be classified (Class 1, 2 or 3) according to the severity of the hazard they represent (flammability, toxicity, corrosivity, temperature).**
- **Exemption may apply, depending on whether a limit on** *(clamp bore x operating pressure)* **is exceeded or not.**
- **Different** *(clamp bore x operating pressure)* **limits apply, depending on fluid class (1, 2 or 3) and state (liquid or gas).**
- **Operating Condition Exemption applies to all pipes operating at or below 1 barg (14.5 psig).**

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Policy On The Provision Of Structural Enclosure Clamps

- ***Class 1 Fluids*** **are those which are:**
  - Flammable (to the extent that they are will self-ignite or ignite in the presence of an ignition source).
  - Highly Toxic.
  - Operating in excess of 300ºC.
- ***Class 2 Fluids*** **are those which are:**
  - Moderately Flammable.
  - Toxic.
  - Moderately Toxic.
  - Corrosive (to human tissue).
  - Operating in excess of 80ºC.
- ***Class 3 Fluids*** **are those which fall outside Class 1 or Class 2 definitions.**

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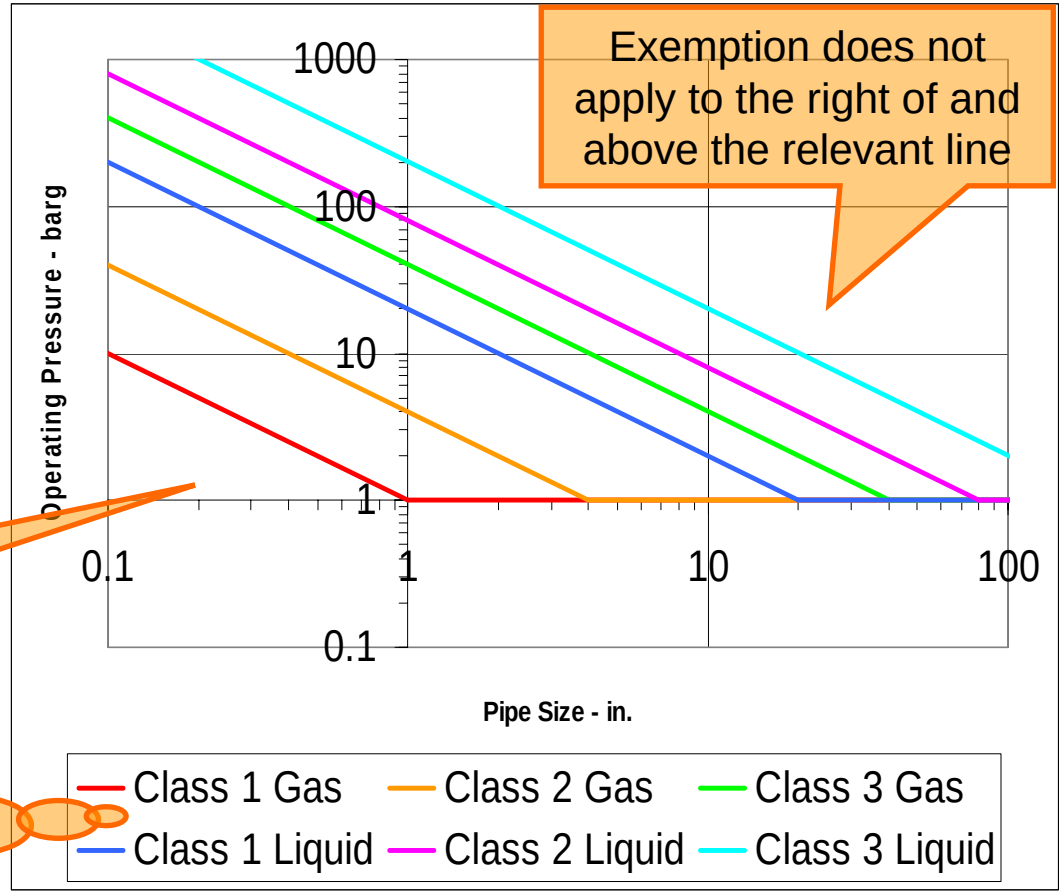
Policy On The Provision Of Structural Enclosure Clamps

Exemption Criteria - Operating Conditions:

Clamp bore x Operating Pressure Limits:



Exemption applies to the left of and below the relevant line

Note: Gases are fluids operating above their atmospheric boiling point

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Policy On The Provision Of Structural Enclosure Clamps

Exceptions and Client Opt-Outs from Policy:

- **Customers may specifically request structural clamps where the policy would not require them.**
- **The policy allows for special cases that can be justified on engineering grounds:**
  - i.e. structural integrity is not compromised, or
  - Consequences of pipe failure are acceptable.
- **Client requests to opt-out for other reasons (for example to reduce costs) will not be accepted.**

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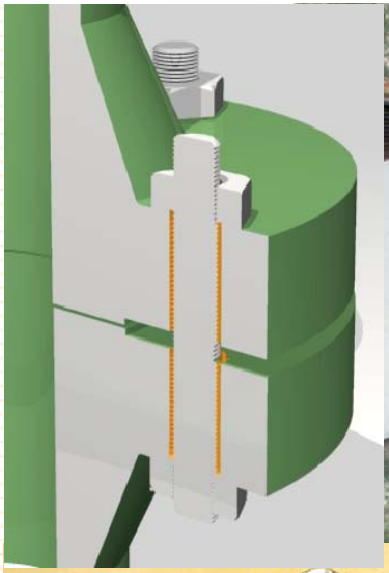
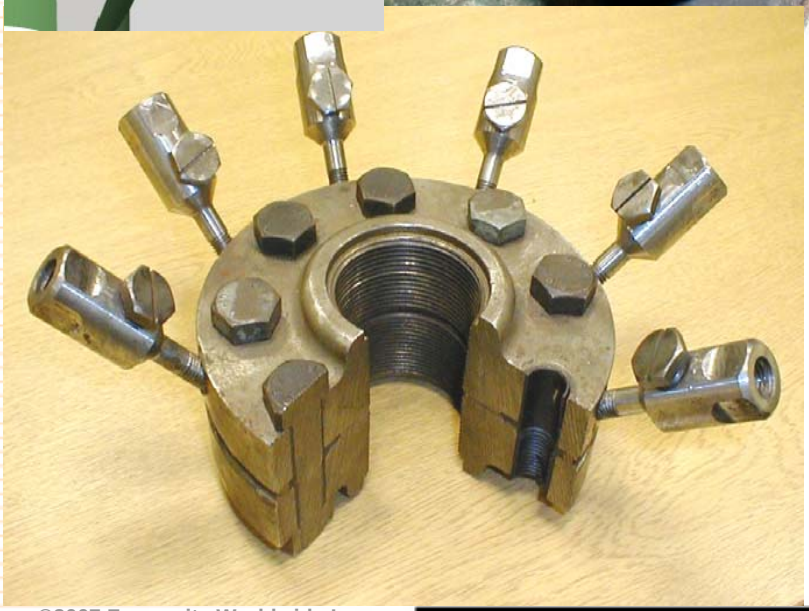
Effect of Compound Injection on Flange Bolting





Leak Sealing of Flanges by Injection of Compound

- **Form a void by closing flange gap with clamp, wire or steel band and packing.**
- **Curing compound (sealant) is injected under pressure into void.**
- **Mould a secondary gasket in-situ**
- **Defect should ideally be sealed at leak path, but pressure boundary may now extend to flange edge**

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Effect of Compound Injection on Flange Bolting

Increasing pressure loads and bolt stresses

- **Pressurising the area outside the gasket (compound injection pressure or line pressure) could potentially cause a significant increase in bolt load.**
  - The area outside the gasket is much larger than the area inside it.
- **In practice, the increase in bolt load is observable, but of modest magnitude (typically of the order of 50%).**
  - Initially, increasing the separation force (by injecting compound) acts to reduce gasket compression until the bolt pre-load is exceeded and the studs start to stretch with a consequent increase in stress.
  - Leak Sealing procedures specify methods which minimise the required injection pressure and/or the area over which it acts.

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Effect of Compound Injection on Flange Bolting

Increasing pressure loads and bolt stresses

- **Flange bolting is very tolerant of additional loads.**
  - Design equations account for hydrostatic pressure forces ***and*** gasket compression loads.
  - Bolt design stresses are typically only a small percentage of yield stress or ultimate tensile stress.
    - **e.g. ASTM A193 grade B7: min. UTS = 862 MPa, Yield = 724 MPa, Design Stress = 172 MPa (at ambient temperature). So design stress is 20% of UTS or 24% of Yield.**
  - Even if bolt load is increased beyond yield, pressure vessel bolts are specified with significant minimum elongation.
    - **e.g. ASTM A193 requires 14% minimum elongation (on a 50.8mm gauge length) for grade B7.**
- **All of the above applies – PROVIDED the bolts are sound**
  - i.e. not subject to waisting or (especially) cracking

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Potential for Flange Bolt Failure during Leak Sealing

Frequency and Consequences

- **Flange bolt failure during leak sealing is very rare, but does occasionally occur.**
- **Usually the consequences are quite modest.**
  - Normally only one bolt fails and then the leak sealing process is halted.
- **If all the studs fail, the consequences could be very serious.**
  - If a significant number of studs in a flange are defective and fail, the remainder could be overloaded and fail in a sequential manner.

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Potential for Flange Bolt Failure during Leak Sealing

Service Conditions and Failure Mechanisms

- **Almost all such incidents occur during re-injection rather than during the initial injection.**
  - Re-injection may be required if a joint re-leaks.
  - Compound injection pressure is typically higher during re-injection.
  - Studs may have been exposed to the process fluid for some time.
- **Boiler feed water is the most common line content amongst the small number of failures.**
- **Stress Corrosion Cracking (or Caustic Embrittlement) is found to be the most common failure mechanism.**

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Potential for Flange Bolt Failure during Leak Sealing

Service Conditions and Failure Mechanisms

- **Incorrect thread lubricant can be an important factor in promoting Stress Corrosion Cracking.**
  - Certain thread lubricants should not be used on boiler feed water service – they can promote SCC whether or not a flange is leak sealed.
- **Many leak sealing compounds contain elements known to be associated with Stress Corrosion Cracking.**
  - e.g. Chlorine, Sulphur, Copper, Zinc.
  - Mostly (but not entirely) these elements are present in a non-leachable (insoluble) form.
  - "Nuclear" grade compounds are available if required, but they are expensive and sometimes do not perform as well as standard compounds.
    - **"Nuclear" grade compounds are analysed to demonstrate compliance with strict limits on potentially harmful elements.**
    - **Primarily for use on the primary circuits of PWRs.**

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Potential for Flange Bolt Failure during Leak Sealing

Mitigation of Potential Hazard

- **For lower pressures, changing of studs prior to leak sealing is possible and is good practice.**
- **Best practice would include the checking of used studs for stress corrosion cracking using portable ultrasonic NDT equipment.**
  - Including and especially for re-injections.
  - High temperature can be an issue.
  - On some plants, NDT of studs before leak sealing activities is mandatory (site procedures).
    - **This is not the common position (or even the majority position) on plants across the UK.**
  - Plant operators, service providers and regulators should unite to make NDT of flange studs a standard part of the flange sealing procedure.

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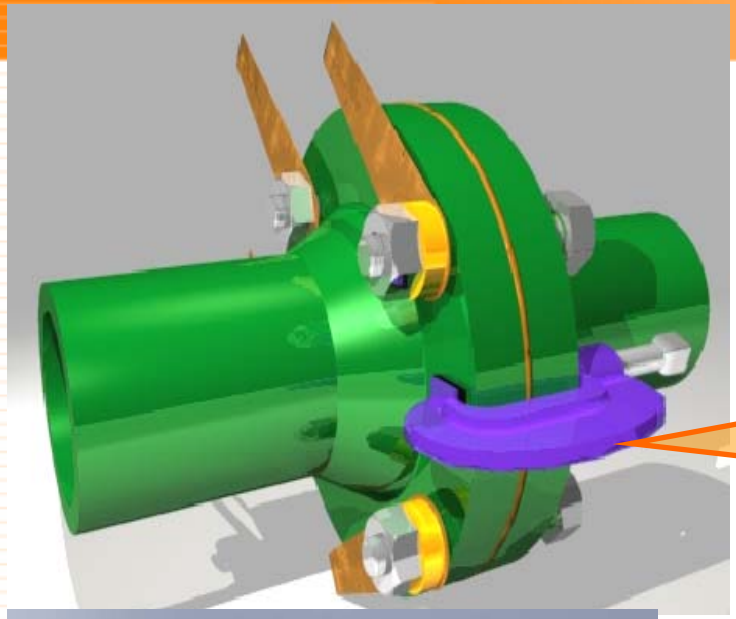
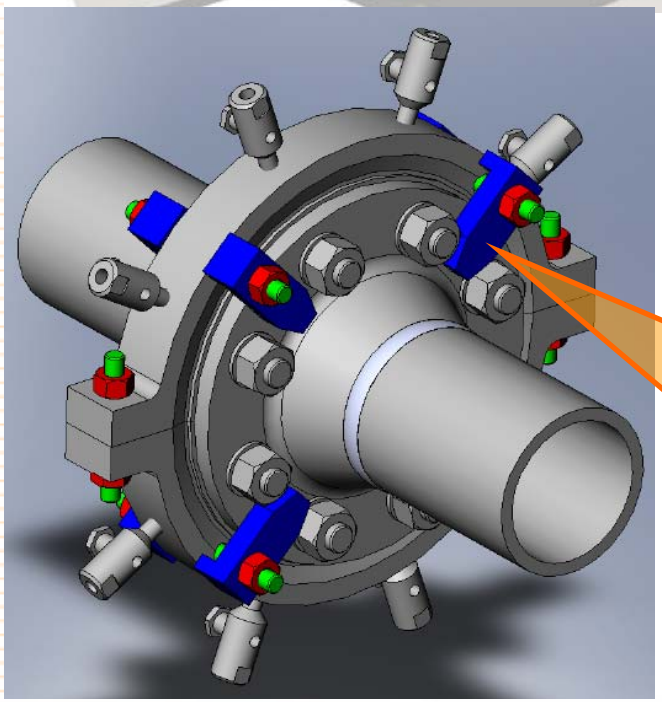
Potential for Flange Bolt Failure during Leak Sealing



Only one “G” clamp shown here – minimum of two and preferably four required



Additional “Heal” clamps to provide additional flange restraint (not to scale)

Mitigation of Potential Hazard

- **Where studs cannot be replaced or checked, it is possible to use additional mechanical restraints**
  - Either separate “G” clamps.
  - Or restraints incorporated into the leak sealing clamp.

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Summary

- **For pipe repairs with enclosure clamps, the most likely** cause of a serious incident is separation of a pipe inside the enclosure.**
  - To avoid the risk of serious injury and financial losses, a robust and conservative policy must be in place to ensure that structural clamps are supplied wherever necessary.
- **For flange repairs, the most likely** cause of a serious incident would be failure of the flange studs.**
  - Possible methods to mitigate the potential hazard include: change out of studs, NDT of studs, or additional mechanical restraints.
  - One of these methods should be employed wherever the condition of the studs is in doubt (special caution with boiler feed water flanges).

** *These statements are qualified by the assumption that any leak sealing clamps have been:*

- ***Properly designed (based on a pressure vessel or piping code as far as possible).***
- ***Properly constructed (using qualified welding procedures and welders).***
- ***Properly installed by skilled and experienced leak sealing technicians.***

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