



Marsh Specialty

Management of temporary repairs

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Section One

Introduction

Background

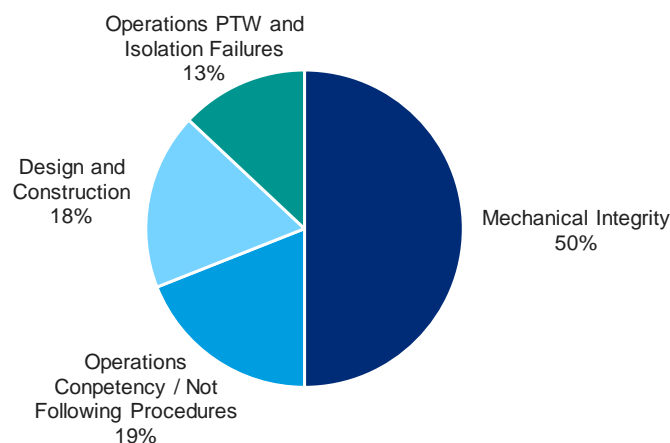
Installation of temporary repairs in the energy and power industry has been an integral activity that has enabled businesses to manage ongoing plant operation for decades.

Whether to address a fault or maintain equipment approaching end of life, the safe installation of robust temporary repairs is essential to asset integrity for the remainder of the turnaround (TA) cycle (life cycle) or until a permanent repair can be completed. In the insurance industry, temporary repair management is discussed during site surveys and is a topic which, on average, client performance scoring is much lower than other mechanical integrity related topics.¹

Objective

In this paper, we will review common repair techniques and focus on the management, inspection, audit, and life-cycle analysis of a variety of temporary repair types. The intention of this document is to raise awareness of industry standards and recommend best practices for management of temporary repairs.

It is good practice to remove repairs and return the plant to original design however, within the industry, the debate relating to the cost of returning equipment to the original design if a repair is technically acceptable is common. A recent study by the Lloyd's Market Association (LMA), found that mechanical integrity failures amount to over a third of major losses. The Liberty Speciality Market loss database shows that half of all claims from 2000-2020 were due to mechanical integrity issues; and, over two thirds of those losses were due to internal and external corrosion of piping systems. For this reason, this paper is focussed predominantly on pipe repair, though the philosophy and basis can typically be applied across fixed equipment.



Reference: Liberty Speciality Markets 2000-2020 loss database

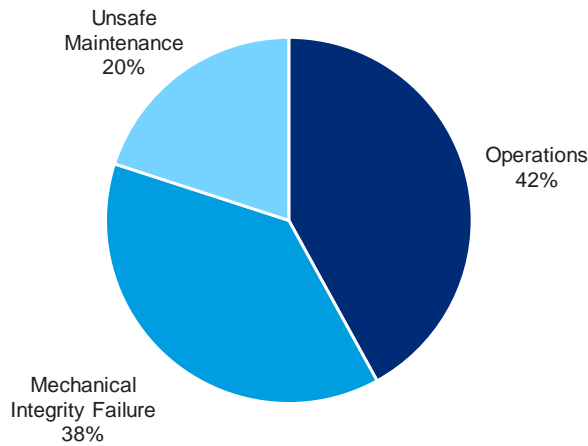
¹ Marsh global energy risk and loss database

Many techniques and designs have been implemented globally in efforts to prevent anticipated leaks or to respond to leaks that have occurred in service. Often, sites opt to carry out in-service repairs in lieu of carrying out a like-for-like repair for two main reasons:

1. **Financial:** Unplanned outages can be costly to the business and result in loss of production. There is potential to have a prolonged outage duration for an unplanned shutdown if materials and skilled labour cannot be sourced or mobilized quickly. Site personnel need to review the ability to release equipment from service without disrupting other operational units when the equipment in question is not spared, for example, parallel pump discharge piping that cannot be isolated from sister pumps.
2. **Balance of risk:** Carrying out an unplanned in-service repair can be lower risk than carrying out an unplanned shutdown, executing a permanent repair, and re-starting a process unit (which may have knock on effects to upstream and downstream operating units). Many industry losses occur during transient operations.

The LMA study, *An analysis of common causes of major losses in the onshore oil, gas & petrochemical industries, September 2016* (updated in June 2020), differentiated between mechanical integrity related losses and non-mechanical integrity related losses. The updated publication, including 37 new major losses in addition to the 100 major losses analysed in 2016, will in future include the previous two categories and add a third – losses due to unsafe maintenance. This is due to a conclusion from the study that one in five major losses are associated with “unsafe maintenance” activities.

2020 – BASED ON 137 LOSSES



Reference: OPERA Webinar - 'AN ANALYSIS OF COMMON CAUSES OF MAJOR LOSSES IN THE ONSHORE OIL, GAS & PETROCHEMICAL INDUSTRIES – June 2020 Update'

Engineered Repairs

Repairs should conform to industry standards, such as *ASME PCC-2, Repair of Pressure Equipment and Piping*. Those which are designed and constructed to recognised standards, and where installation is controlled under a management of change (MOC) process, are considered as “engineered repairs”. Most repairs are engineered designs, which are substantiated by calculations, laboratory testing, and through proven experience; other fit-for-purpose, non-engineered repairs are intended to improve the current condition, with no guarantee of success. The latter are often deemed acceptable from an immediate improvement perspective, providing the process safety risk is deemed acceptable. This is largely based on the process fluid (for example, *ASME B31.3 Category D Fluid*) however, major incidents have occurred in the industry due to loss of cooling water or utility services. For this reason, this paper does not recommend non-engineered repairs. It is recommended that any non-engineered repairs be risk assessed and documented by formal MOC. During insurance surveys, risk engineers will ask to view the current temporary repair list and mechanical repair clamp register. The only non-engineered repair technique captured in this paper is the mechanical line clip, due to its ubiquitous nature in the energy and power industries.

The ASME PCC-2 covers the following:

- Part 1: Scope, organization, and intent.
- Part 2: Welded repairs.
- Part 3: Mechanical repairs.
- Part 4: Non-metallic and bonded repairs.
- Part 5: Examination and testing.

The structure of this paper will use terminologies consistent with ASME PCC-2 and will focus on recommendations for management systems and experiences from industry to aid engineers in their understanding of the capabilities and limitations of the design.

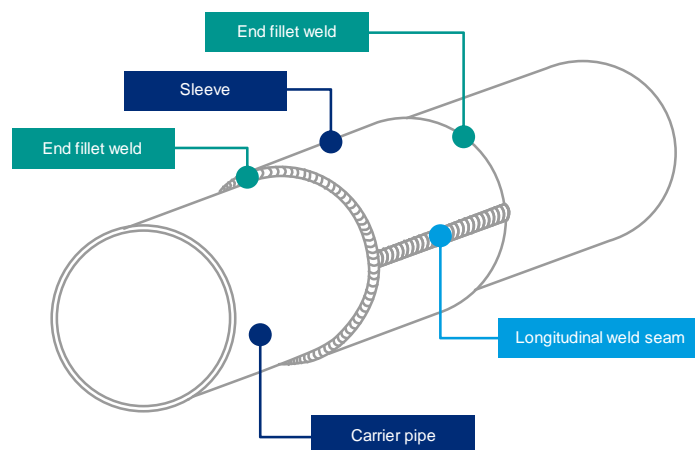
Section Two

Repair Types – An Overview

This section of the paper provides an overview to common types of repair techniques, summarising design features and limitations to their application.

Full Encirclement Steel Reinforcing Sleeves for Piping (ASME PCC-2, Article 206)

Full encirclement sleeves are repairs used to encompass thinned or leaking sections of straight pipe. Two halves are placed around the pipe, prior to welding each circumference and the longitudinal welds. The repair pieces can be made from rolled plate material or the next size up in pipe diameter (depending on geometry). A tapped vent hole is used to allow welding gases to be released, which is later plugged and seal welded. It is possible to install a pressure gauge to the tapped vent hole to facilitate a hydrostatic test. It should be noted that, if the parent pipe is thinned, the pressure test could result in a perforation of the thinned area – this should be captured in the MOC risk assessment. The joint efficiency of the assembly should be reviewed by a mechanical engineer during the design process, as the introduction of butt and longitudinal welds will reduce the joint efficiency.



Flange Repair

Flange Modification (ASME PCC-2, Article 305)

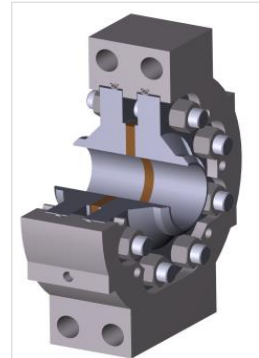
Damage to gasket faces can occur from mechanical damage during TA and maintenance activities and in some cases, during service. This can result in loss of containment across the joint face of a set of flanges. This type of leak can cause erosion to the flange, leading to further degradation of the flange and increased rate of process fluid volume released. On raised face weld neck flanges, it is possible to upgrade the gasket from an ASME B16.20 spiral wound to an ASME B16.20 ring-type joint (RTJ). Refer to *ASME PCC-2* for more detail on how to execute this work.

Flange Machining

If gasket upgrade is not required, a flange can be repaired and re-instated by machining the joint face down until the defect has been removed. In this instance, it is important to understand why the defect occurred and plan for future deterioration. Considerations relating to machining down a flange face beyond the defect include over-stressing the flange, flange rotation, optimal gasket seating stresses, desired surface finish. It is possible to machine the flange down and follow-up with applying a weld build-up layer to the flange face, followed by machining the finish.

Mechanical Flange Clamp (ASME PCC-2, Article 306)

A third option for flange repair is to install a mechanical flange clamp onto the flange. This design is similar to the mechanical clamp repair philosophy described below but is fitted to flanges. It is possible to design end restraints to prevent axial blow out where bolts have deteriorated or have the potential to continue to deteriorate in service. Injection of the flange clamp is done in order to offer a seal between mechanical components. The resin injection inlet remains installed to allow subsequent re-injections. These reinjections have the potential to increase stress on the bolting and requires a detailed review, potentially limiting the number of reinjections for the clamp to avoid bolting issues or crushing the pipe. An internal company standard for re-injection procedures is recommended. Encasing bolts within the flange clamp can create environments where concentrations of amines, caustics or hydrogen fluoride can collect and result in stress corrosion cracking. In this instance, full-bore rupture of the flange is possible if end restraints are not installed.



Photographs courtesy of TEAM Inc.

Mechanical Clamp Repair (ASME PCC-2, Article 306)

Mechanical clamp repairs, also known as 'box' repairs, are used extensively in the energy and power industry. They can be installed on active leaks and on anticipated leak locations. They are engineered repairs and can be considered permanent, providing the MOC captures all elements of the future operation. Deviations from the MOC would require a review of these repairs. The body of these repairs, typically designed to ASME VIII, have design conditions equal to or in excess of the design condition of the parent pipe. Clamps are installed by specialist third party contractors. Different sections of the clamp are bolted together and sealed with (often compressed graphite) gaskets. Clamps can be installed with a resin injection, which can act as a secondary seal. Dependant on the materials used, the resin, once set, may not be fit to be subjected to thermal transient operations, such as TAs or unit trips, unless specified at the design stage.



Photographs courtesy of TEAM Inc.

Engineered Composite Wraps (ASME PCC-2, Article 401/402)

Engineered composite wraps are designed to be applied externally to piping systems by applying several layers of epoxy resin reinforced sheets. The epoxy resin material requires curing time and in some cases, activation to cure. The landing area of composite wraps are the locations used to fix the wrap in place, which is the location where surface finish is most critical. They can be installed on active leaks and on anticipated leak locations. Engineering requirements are set by *ASME PCC-2* and *ISO 24817 – petroleum, petrochemical and natural gas industries – composite repairs for pipework – qualification and design, installation, testing and inspection*. Each repair should be considered bespoke and will require a unique MOC assessment with engineering input. Installation quality assurance (QA) is critical for an effective wrap and prior review of feasibility of pre-requisites defined by the composite wrap manufacturer should be reviewed and approved as part of the MOC process. Some companies opt to install composite wraps on low consequence equipment or thinned hydrocarbon piping, as opposed to failed. For example, when a specific surface finish is required. Maintenance and operations must agree on the tools used from a permit perspective, while achieving the results required. The inclusion of a permit signatory is recommended at the design stage. *EEMUA 199²* provided guidance on this subject.



Photographs courtesy of TEAM Inc.

² The Engineering Equipment and Materials Users Association (EEMUA) aims to improve the safety, environmental and operating performance of industrial facilities.

Pipe repair clips

Pipe repair clips, also known as pipe savers, are common emergency repair components, typically stored in various sizes in maintenance stores. Suppliers manufacture these clips in various lengths and diameters from small bore, up to and over Ø 3000mm. The clip can be opened to allow it to wrap around the thinned or leaking location, before being fixed in place by bolting the sections together. The seal is achieved by securing the internal rubber lining in place. Installation is relatively straight forward and can be carried out by skilled maintenance technicians however, formal training should be in place, including refresher training and documented authorization to carry out these repairs.

Material compatibility with the process fluid should be a key consideration. Rubber lining options typically include ethylene propylene diene monomer (EPDM), hydrogenated nitrile rubber (HNBR), nitrile rubber (NBR) and Viton™. In addition to material compatibility, temperature is also a key factor when selecting an appropriate rubber seal. Rubber seals can withstand moderately cool and warm temperatures (-40°C to 150°C depending on the material properties) before becoming brittle and failing to hold a seal.

The installation technique is critical when responding to external corrosion scale due to the risk of disturbing the corrosion and worsening 'scab'. It is possible to develop pre-engineered emergency procedures for repair clip installation by maintenance teams, providing a rigorous MOC has been developed with clear restrictions, including process fluid restrictions.

Marsh recognises this as a common short-term emergency repair technique but recommends the use of this repair technique should be restricted to:

- Piping systems with a maximum flange rating of 150#.
- Applications on low consequence of failure equipment.
- *ASME B31.3 Category D* fluid services.

Pipe clips (or savers) are occasionally installed by operations or maintenance staff and either forgotten or (because of lack of assessment), crush the pipe resulting in a larger leak. [See Example #1.](#)



Photo 1 courtesy Cascade. Photo 2 courtesy Teekay Couplings

Section Three

Change Management and Operating Procedures

Management of Change

Management of Change (MOC) is a well established method of assessing modifications to plant design or deviating from established standards or routines. Installations of temporary repairs on sites has the potential to introduce new risks and should be managed and documented accordingly. MOC should be carried out for all temporary repairs. In terms of documentation, it is good practice to use the MOC database to record all repair installations. The MOC database should be considered the master list however, separate data downloads from the database can be useful for planning of inspection, maintenance and TA activities. Operations should hold a record of live repairs on their process unit, which diligent operators would be expected to informally inspect during occasional rounds. It is recognised as best practice to hold a photograph of the repair with a clear background to reference, in order to help locate the repair. This should be in the MOC document and in the operations temporary repairs file. For higher risk repairs, inspection during operator rounds should be captured in the MOC and specifically mentioned in operator rounds checklists. Best practice is for the inspection department to maintain a list of temporary repairs, with unique identification numbers and report their status as a process safety key performance indicator (KPI) to senior management on a monthly basis. The numbered temporary repairs are a useful process safety KPI during insurance surveys should an insurer ask for this information. The inspection department should also inspect the repairs, though the frequency may be less often but more detailed with the use of non-destructive testing (NDT) and reference to the mechanical design.

A multi-disciplined team should be assigned at the design stage, when the MOC is being developed. It is important to involve all disciplines who may need input at this stage in order to have a holistic understanding of the repair strategy.

The MOC should define the retirement plan for the repair, as opposed to simply setting an end of life date. For example, for pipe repairs, installation of new flanges and replacing the damaged piping section with a pre-fabricated spool piece would be typical. Installation of flanges requires MOC consideration, including process preparation, hot work, pressure testing and emissions through flanges. By considering restrictions related to repair removal, some prospective repair options may be written off at the design stage, on the basis that they cannot be removed.

For more guidance on MOC, refer to Marsh's paper, [Risk Engineering Position Paper: Management of Change \(MOC\)](#).

Considerations

Mechanical considerations

Typical mechanical considerations when reviewing the design of potential temporary repairs include:

- Material compatibility between the repair components and the process fluid.
- Thermal, mechanical and pressure cycles.

- Joint efficiency changes e.g. full encirclement steel reinforcing sleeves.
- Requirement for end restraints in case of full bore rupture.
- Repair weight and pipe support effectiveness.
- Ongoing internal degradation.

In addition to those listed above, the mechanical engineer should review the repair design drawings and calculations, and assess the suitability in accordance with corporate and industry standards.

Operational Considerations

The method, task risk assessment and control required to install a temporary repair should be reviewed and authorised the same as any other maintenance activity on site.

Any impact on normal operation of the system to which a repair is applied should be captured in the MOC document governing the change. This may result in temporary modifications of safe operating procedures, increased monitoring schedules etc.

The operations team should be involved in defining response guidelines in the event the temporary repair deteriorates or fails while in service, to ensure the system can be returned to a safe state.

Routine inspections of repairs on critical equipment should be included on operator rounds checklists.

[EEMUA 199: On-line leak sealing of piping: Guide to safety considerations](#) is a useful document to ensure installation of on-line leak sealing of piping is done in a safe manner.

Maintenance Considerations

Access requirements, such as scaffolding, need to sufficiently enable the technician to access all required areas. Ensure the maintenance planner has a good understanding of the scope of work from the technician's perspective. Liaising with the MOC team is a key step in understanding the required scope of work.

Surface preparation is critical for installation of composite wrap repairs. This should be detailed in the MOC. Missing information relating to surface preparation should prompt a questions from maintenance to the mechanical engineer, rather than lead to an assumption that it is not relevant, particularly for piping sections suffering from external corrosion.

Coordinating skilled labour should be planned in advance of the repair. Key technicians required to install repairs can included mobilization of NDT technician or specialist repair installation technicians.

In the planning and procurement stage, maintenance should consider which materials require longer ordering lead times, such as specialist tools, specified materials, or bespoke gaskets. Maintenance involvement in the MOC development stage can improve efficiency of repair planning and execution by sourcing materials earlier and identifying unacceptably long lead times.

Pre-fabricating replacement flanged spool pieces is good practice, as it enables opportunity replacement during unplanned outages (providing resource levels are sufficient to respond to the reason for the unplanned outage).

The maintenance department should ensure they have an efficient means of tracking repair removal deadlines and use a numbering system that is consistent with the source of the recommendation. Having effective means of tracking repairs in place and their removal timeline will assist with planning repair removals, as well as feed into KPIs.

Inspection Considerations

Consider what non-destructive techniques are available to inspect the condition of key components of the repair and review their effectiveness.

The retirement date of the repair should be considered and the reason for that date should be well documented. If the date is aligned to a TA but is fit for half of a continued run length, this should be stated in the MOC.

Regulatory considerations should capture the local authority's requirements in association with temporary repairs. In the event of an audit, the MOC should document the technical basis for endorsing continued operation.

Deferral of the replacement of temporary repairs should be well documented with all disciplines used in the development of the original MOC, plus any other relevant disciplines when considering a deferral of the replacement. For Marsh guidance on inspection deferrals, refer to [Best Practices When Postponing Inspections in Downstream Energy](#).

It is typical to inspect pipe repair clips (pipe savers) on a 3-6 monthly frequency to verify the integrity of the repair. The frequency of inspection is typically based on risk.

Standard and Emergency Operating Procedures

It is expected that established sites with best in class management systems will have established, reviewed and self-audited standards and emergency operating procedures. In terms of temporary repairs, sites can develop maintenance routines with pre-engineered leak response strategies. Loss of primary containment is a common occurrence on energy and power sites globally, particularly on lower consequence systems. By developing an emergency repair strategy for a pre-defined and unambiguous list set of piping systems, site personnel can respond to leaks and reduce the escalation of consequence. Input from a mechanical integrity engineer is required prior to executing the repair however, the extent of reactive work will be reduced. The following variables should be captured in any pre-engineered repair strategies:

- Pipe metallurgy (recommend limiting this to carbon steel i.e. ASTM SA-106 Gr B).
- Pipe diameter (recommend limiting this to Ø 150mm).
- Repair type (recommend limiting this to line clips only i.e. rubber lined, metal outer casing with bolted installation).
- Process fluid (recommend ASME B31.3 Category D fluids. Consider all loss scenarios).
- Repair component metallurgy. A high performance fluorelastomer rubber lining (for example, Viton ®) may be more resilient to some process materials, such as aromatic hydrocarbons. Compatibility of surfaces potentially exposed to the process fluid must be compatible to prevent deterioration and subsequent leak.

It is recommended that the maintenance organisation have pre-defined parameters to guide the execution of emergency repairs. The level of autonomy should be carefully considered, including which discipline input is required. For example, loss of cooling water to a reactor can have catastrophic process safety implications but a cooling water leak can be perceived as relatively benign without proper understanding of the process.

Section Four

Repair Selection and Retirement Strategy

Repair Type Selection

Many repair techniques are likely to be available in response to a wide range of scenarios. It is recommended that all are considered, and the selection process is well documented with a basis for the decision. A useful reference table has been added as [Appendix B](#), which provides an overview of compatibility between repair types versus degradation mechanisms. The table is from the 2015 edition of *ASME PCC-2*. The table was removed in the 2018 edition and “limitations” of repair types have been incorporated into the individual “articles” in the 2018 Standard.

Retirement

The classifications of a repair are often defined as permanent or temporary (defined life) – the Marsh definition of these is summarised in [Appendix C](#).

For operating plants with scheduled TAs or overhaul outages, it is common to align the repair removal date to these periods of increased maintenance. Through the planning stage, the requirement to remove these repairs is often scrutinised by the business. During TAs and overhaul outages, maintenance activities are at their busiest and efficient planning is critical. To drive cost-efficiency, management may challenge the need to replace a temporary repair that is not currently leaking. For this reason, sites should define their own risk-based maintenance strategy.

Low consequence equipment is often serviced with more basic repairs (for example, line clips) with a lower confidence of long-term effectiveness. Lower consequence piping is often cheaper to repair due to materials used for construction and fabrication (for example, flange-to-flange piping replacement). Higher consequence equipment is typically repaired to code (for example, *ASME PCC-2*), with well-documented MOC and significant engineering behind the design. While these are well designed installations, they need careful consideration to justify continued operation that exceeds the initial repair retirement date. An MOC review involving all disciplines from the original MOC, is required to update the original MOC in order to agree a repair replacement date. For example, so that an appropriate decision can be made about either postponing the replacement until the next TA/overhaul outage or re-defining the repair as a ‘permanent’ feature with a bespoke inspection and maintenance strategy.

Section Five

High Level Governance

It is recommended to capture temporary repairs in monthly KPIs.

An industry recommended practice, *API 754, process safety performance indicators*, provides an overview on how to define and record four tiers of incidents. The requirement for the installation of a temporary repair is often a tier three incident, depending on the extent of the impact leading to the requirement for a repair. The repair could have been installed following a tier one or two incident. In some cases, the impact is low and could be considered a tier four incident however, consideration should be given to the worst case scenario. For example, for an initially benign-sounding cooling water leak, the worst case scenario may be loss of cooling water to a process plant, resulting in a process safety incident. For more guidance on process safety performance indicators, refer to Marsh's paper [Risk Engineering Position Paper: Process Safety Performance Indicators \(PSPIs\)](#). *API RP 585, pressure equipment integrity incident investigations*, is a recommended practice (RP) intended to allow users to improve the effectiveness of their incident investigations. This RP will help identify when an investigation should be carried out and how to best utilise the information available to provide a range of effective solutions to propose to the business. It is recommended that installations of all repairs be considered for investigation, regardless of whether the deterioration of the piping system has resulted in a loss of containment.

Key performance indicators for temporary repairs should typically include:

- The total number of temporary repairs on site.
- The total number of repairs in hydrocarbon service.
- The number of repairs that are leaking or weeping (ineffective repairs). The target should be zero.
- How many temporary repairs are in operation beyond their retirement/replacement date (with reference to the MOC document). The target should be zero.
- Whether the repair was the result of a loss of containment or a near miss. Investigations should be carried out by site personnel for recurring issues (for example, common degradation mechanisms that lead to loss of containment) and high consequence of failure loss and near miss scenarios.
- The degradation mechanisms that caused the leaks. Common mechanisms should be investigated, with a view to acting on overly common mechanisms, for example, soil/air interface corrosion or corrosion under insulation.
- The total number of repairs that have been in service prior to the most recent TA. The target should be zero (this will highlight problem repairs).

Effective incident reporting and investigation can lead to effective longer-term improvements and warrant project investment. One such example may be, if one line has suffered from repeat failures and has several temporary repairs, there will come a point when no additional repairs can be installed, either due to geometric restraints, integrity of remaining pipe or weight of the additional repairs. Effective incident investigation and reporting will capture the holistic risk and could warrant the investment in a replacement piping system, with upgraded metallurgy. See Example #5 below.

[Appendix A](#) contains a checklist, intended to assist sites with their temporary repair management strategy. The checklist references corporate standards, MOC and audit practices.

Section Six

Examples from industry

1 Pipe clip installation error Increased leak rate during installation

Insulation was removed from an off-site benzene piping system, as part of a scheduled CUI inspection. Upon removal of a section of insulation, the piping inspector identified thick corrosion scale, localized along a ~100mm x 250mm stretch at the underside of the horizontal pipe. A benzene smell was reported to operations, who then confirmed low levels of benzene were in the corrosion location. The pipe, more than 2km in length, was used for loading benzene to the marine terminal for export. An emergency line clip was installed as a temporary solution until a planned repair could be carried out. The line clip disturbed the corrosion scale, which resulted in a significantly increased loss of containment. Isolation and permanent repair was carried out. The local regulator carried out an investigation. Operations were impacted due to inability to export benzene under normal operation, and shipping demurrage was incurred.

2 Composite wrap repair Response to unexpected cracking

A non-post-weld heat-treated carbon steel piping system carrying liquid petroleum gas (LPG) suffered a loss of containment due to amine stress corrosion cracking (ASCC). A process upset resulted in liquid carryover of monoethanolamine (MEA) from a vertical amine scrubber tower into the 100m long overhead piping system, which was not designed to carry MEA. This led to a through wall crack and LPG release to the atmosphere. The vapor cloud did not ignite and the process unit was safely shutdown. The fluid catalytic cracking unit (FCCU) was shut down as a result, as well as impacting other units across the refinery. Once the degradation mechanism was identified, the piping system was inspected using phased array ultrasonic testing (PAUT). Cracking was identified on several butt welds and composite wrap repairs were installed in accordance with industry standards. The plant was re-commissioned, while operating under a risk assessment, as the risk of continued ASCC resulting in full circumferential rupture was recognized. The composite wraps were not designed to provide end restraint in the event of full circumferential rupture. The plant was recommissioned on the basis that retrospective end-restraint installation would be installed during operation. This was later deemed to be an unsuitable proposal from a personnel exposure risk perspective. The line could not be inspected for continued deterioration due to the wrap installation, nor could the risk of full bore rupture be mitigated. The operational risk assessment had to be reviewed due to the increased operational duration (until the next planned TA) to replace the piping system. This required an increased level of authority to approve continued operation in order to maintain operation. Refer to *API RP 945* for recommended practices for “avoiding environmental cracking in amine units.”

3 Boiler pipe leak 1500# flange repair

A flange leak occurred on a 1500# piping flange, on the high-pressure boiler feed water piping system. Continued operation was managed while a repair plan was developed but the leak deteriorated over a period of days. The gasket type was a ring type joint (RTJ) and the leak deterioration was due to erosion across the leak path. The unit was shut down to facilitate the installation of a resin injected mechanical clamp repair by a third party specialist. The repair was due to be removed at the next TA. The repair installation and subsequent start-up was successful however, months later a unit trip resulted in the repair leaking. The leak path was between the gasketed section of each half of the mechanical repair clamp. A welded repair was installed to reduce the risk of recurrent issues. The root cause of the repair failure was that the MOC did not consider unplanned unit trips, but allowed for a non-ductile resin to be used.

4 US\$515 million loss Inadequate weld repair leads to a vapor cloud explosion

Just prior to the rupture of a 55-foot high, 8.5 foot diameter monoethanolamine absorber column, a refinery operator noted a six inch horizontal crack at a circumferential weld that was leaking propane. As the operator attempted to close the inlet valve, the crack spread to about 24 inches. The area was being evacuated and the plant fire brigade was arriving when the column failed. Propane at 200 psig and 100°F propelled most of the 20 ton vessel 3,500 feet, where it struck and toppled a 138kV power transmission tower. The weld separation occurred along a lower girth weld joint made during repairs to the column 10 years earlier. The vessel was constructed of one-inch thick ASTM SA 516 Gr 70 steel plates rolled and welded with full penetration submerged arc joints, but without post-weld heat treatment. The explosion resulted in severe fires in the unsaturated gas plant, as well as fires in the fluid catalytic cracker (FCC) and the alkylation units. After about 30 minutes, a boiling liquid expanding vapor explosion occurred in a large process vessel in the alkylation unit. A piece of the vessel travelled 500 feet, shearing off pipelines before striking a tank in the water treatment unit. Another fragment landed in a unifying unit over 600 feet away, causing a major fire. The first explosion, believed to be from a vapor cloud, broke windows up to six miles from the plant. The explosion also caused extensive structural damage to refinery service buildings and disrupted all electric power at the refinery, rendering a 2,500 US gallons-per-minute (US gpm) electric fire pump inoperable. One explosion sheared off a hydrant barrel, resulting in reduced fire water pressure from the two 2,500 US-gpm diesel engine driven fire pumps, which were operating at the time. The refinery's blast resistant control center, approximately 400 feet northeast of the absorber, sustained little structural damage. An estimated 30 paid and volunteer public fire departments, together with equipment from refineries and chemical plants within a 20 mile radius, responded promptly. Many of the pumpers took suction from the adjoining canal and from a quarry. The pumpers and a 12,000 US-gpm pump on a fireboat eventually provided water at pressures sufficient for fire-fighting.

5 Extensive use of pipe repair clamps on amine system Unexpected failure mode

A carbon steel pipe feeding lean MEA to a hydro desulphurization unit had been installed with either inadequate or no post-weld heat-treatment. The pipe had suffered from amine stress corrosion cracking (ASCC) at several butt welds on straight sections of the piping system. In most cases, the piping system could be effectively repaired on a temporary basis with a pipe repair clip under MOC. This was deemed to be a suitable fix and line replacement was screened out of the TA scope, on the basis that the line was fit-for-purpose and no consequence escalation was foreseen. The inspection program captured the risk of ASCC and an improved inspection technique was implemented. Phased array ultrasonic testing was used to inspect for sub-surface cracks, which identified significant circumferential cracking. The risk of full-bore rupture was captured in an operation risk assessment, allowing the unit to remain in operation until a permanent fix could be installed. Restricted access to the unit meant monitoring of crack growth could not be permitted. The pipe was eventually replaced with carbon steel, which was stress relieved in accordance with *API 945* and *NACE SP0472*.

Section Seven

References

- [100 Largest losses in the hydrocarbon industry, Marsh, 2020](#)
- [An analysis of common causes of major losses in the onshore oil, gas & petrochemical industries, September 2016, Lloyd's Market Association](#)
- [API 754, Process safety performance indicators, April 2016](#)
- [API 580, Risk-based inspection, 3rd edition, February 2016](#)
- [API RP 585, Pressure equipment integrity incident investigation, 2014](#)
- [ASME PCC-2, Repair of pressure equipment and piping, 2018 edition, American Society of Mechanical Engineers](#)
- [ASME B31.3, Process piping. American Society of Mechanical Engineers](#)
- [Best practices when postponing inspections in downstream energy, Marsh, July 2020](#)
- [EEMUA 199: On-line leak sealing of piping: guide to safety considerations](#)
- [EEMUA 231: The mechanical integrity of plant containing hazardous substances](#)
- [ISO 24817 – Petroleum, petrochemical and natural gas industries — composite repairs for pipework — qualification and design, installation, testing and inspection](#)
- [Risk engineering position paper: Management of change \(MOC\), Marsh](#)
- [Risk engineering position paper: Process safety performance indicators \(PSPIs\), Marsh](#)
- [Temporary/permanent pipe repair – guidelines. Health and Safety Executive, 2001](#)



Appendix A

Temporary Repairs Management Systems – Self Assessment Checklist

The checklist below can be used by the appropriate person on site to assess the comprehensiveness of the overarching processes and management systems for temporary repairs. If you answer NO to any of the questions below, you must ensure the issues are resolved. If required, seek advice from a subject matter expert.

Question	Yes	No
Corporate Standards		
Does an internal corporate standard exist for temporary repairs?		
Is this corporate standard in accordance with industry standards, for example ASME PCC-2?		
Is the corporate standard reviewed and updated on a frequency defined by corporate guidelines and no more than on a five yearly frequency?		
Management of Change		
Is a repair MOC template (or a similar review and approval process) used to manage and document the use of temporary repairs?		
Do the following disciplines provide input in the design/development stage of temporary repair MOCs (note that only the discipline should decide on whether “not applicable” applies to their input):		
Inspection/corrosion engineer		
Equipment inspector		
Mechanical engineer		
Process engineer		
Operations supervisor		
Process safety engineer		
Maintenance lead		
Process unit manager/asset owner		
Is a risk assessment carried out for each individual repair, covering personnel health & safety, process safety, financial and environmental risks for installation, commissioning, operations and de-commissioning stages?		

Question	Yes	No
Has all “input data” been validated, such as ensuring master piping and instrumentation diagrams (P&IDs), piping isometrics and design/operating conditions are accurate by carrying out field visits and reviewing process data records?		
Has a retirement strategy been determined, including a timeline to procure materials, release equipment from operations and physically return the equipment to its original design?		
Does the risk assessment capture all operating conditions; including normal operation, upset conditions, normal start-up and shutdown, idle time, emergency shutdown and subsequent start-up?		
On each occasion that a repair is required, is the design deemed technically suitable for the future operating parameters by the disciplines listed above?		
Have all repair options been considered and has the reason for the repair type selection been documented?		
Is a higher level of approval required for repairs to equipment with inherently high consequence of failure scenarios in terms of negative affects to health and safety, environmental impact, financial loss and reputational damage?		
Is the repair strategy aligned with the commercial expectations of the unit being shutdown?		
Does the company have cross departmental alignment relating to the repair strategy, for example, does the TA group agree that the scope of work can be carried out during the proposed shutdown?		
Are specialist repair contractors assessed prior to selection, ensuring they are an approved vendor that pass internal standards and are ISO 9000 accredited?		
Audit		
Is a temporary repairs master list used for record keeping?		
Are the number of temporary repairs documented and visible to management and staff via the company’s KPI communications?		
Are pre-commissioning QA steps in place to ensure the repair has been executed as per the MOC document?		
Do training modules and formal authorizations exist for individual disciplines listed above?		
Are operator and asset integrity inspection rounds incorporated into the standard operating procedures and the inspection program, respectively?		

Appendix B

ASME PCC-2-2015– Guide for the Selection of Repair Technique

2015 Article Number	Article Title	General Wall Thinning	Local Wall Thinning	Pitting	Gouges	Blisters	Lamina-tions	Circum-ferential Cracks	Longitud-inal Cracks	Other
2.1	Butt-welded Insert Plates in Pressure Components	Y	Y	Y	Y	Y	Y	Y	Y	Note 1
2.2	External Weld Overlay to Repair Methods for Internal Thinning	N	Y	Y	Y	N	N	N	N	Note 2
2.3	Seal-welded Threated Connections and Seal Weld Repairs	NA	NA	NA	NA	NA	NA	NA	NA	Note 3
2.4	Welded Leak Box Repair	N	Y	Y	N	N	N	R	R	Note 4
2.6	Full encirclement Steel Reinforcing Sleeves for Piping									
	Type A sleeve	Y (note 5)	Y (note 5)	Y (note 5)	R	N	N	N	N	
	Type B sleeve	Y	Y	Y	Y	Y	Y	Y	R	
2.8	Alternatives to Traditional Welding Preheat	Y	Y	R	Y	R	Y	R	R	Note 6
2.9	Alternatives to Postweld Heat Treatment	Y	Y	Y	Y	S	Y	Y	Y	Note 7
2.10	In-Service Welding Onto Carbon Steel Pressure Components or Pipelines	N	N	N	N	N	N	N	N	Note 8
2.11	Weld Buildup, Weld Overlay, and Clad Restoration	N	Y	S	S	S	N	N	N	
2.12	Fillet Weld Patches	N	Y	Y	Y	S	N	R	R	
2.13	Fillet Welded Patches With Reinforcing Plug Welds	N	Y	Y	Y	S	N	R	R	
2.14	Threaded or Welded Plug Repairs	N	Y	Y	Y	N	N	Y	Y	
3.1	Replacement of Pressure Components	Y	Y	Y	Y	Y	Y	Y	Y	
3.2	Freeze Plugs	NA	NA	NA	NA	NA	NA	NA	NA	Note 9
3.3	Damaged Threads in Tapped Holes	N	N	N	N	N	N	N	N	Note 10
3.4	Flaw Excavation and Weld Repair	NA	NA	Y	Y	Y	Y	Y	Y	Note 11
3.5	Flange Refinishing	N	N	Y	Y	S	N	Y	N	Note 12
3.6	Mechanical Clamp Repair	N	Y	Y	R	N	N	R	R	Note 2 & 13
3.7	Pipe Straightening or Alignment Bending	N	N	N	N	N	N	N	N	Note 14
3.8	Damaged Anchors in Concrete	NA	NA	NA	NA	NA	NA	NA	NA	Note 15
3.11	Hot and Half Bolting Removal Procedures	N	N	N	N	N	N	N	N	
3.12	Inspection and Repair of Shell and Tube Heat Exchangers	Y	Y	Y	R	Y	N	Y	Y	
4.1	Nonmetallic Composite Repair Systems: High-Risk Applications	Y	Y	Y	R	Y	Y	R	R	
4.2	Nonmetallic Composite Repair Systems: Low-Risk Applications	Y	Y	Y	R	Y	Y	Y	R	
4.3	Nonmetallic Internal Lining for Pipe: Sprayed Form for Buried Pipe	Y	Y	Y	Y	Y	Y	Y	Y	
5.1	Pressure and Tightness Testing of Piping and Equipment	N	N	N	N	N	N	N	N	Note 16
5.3	Nondestructive Examination in Lieu of Pressure Testing for Repairs and Alterations	NA	NA	NA	NA	NA	NA	NA	NA	Note 17

Y = generally appropriate
 S = may be acceptable, but is not generally used for this condition
 R = may be used, but requires special conditions
 N = non generally appropriate
 NA = not applicable

Reference: ASME PCC-2-2015, Table 1
 The table above is included with permission from ASME and is recognized as a useful visual reference to initial repair selection.

NOTES

- This method may apply to replacement of nozzles, flat spots, and dents.
- See Part 2, Article 2.1, Limitations.
- This repair technique applies to seal welded threaded joints for leak tightness.
- Welded leak box repair applies to leaking flanges, valves, pipe components, and welded and mechanical joints.
- For internal defect, the cause of defect shall be understood or arrested, or a Type B sleeve is recommended.
- Alternative provisions for welded repair.
- This technique is used for isolating sections of pipes.
- Also may apply to new construction or to all methods requiring welding.
- Generally appropriate for surface welding on carbon steel substrates.
- Repair of damaged threads in stud holes.
- Also applies to the repair of hardened surfaces.
- Radial cracks.
- Gasket and packing leaks = Y.
- Pipe straightening.
- Repair of damaged anchor in concrete.
- This is not a repair technique; however, it may apply to most methods of repair.
- This is an alternative to pressure testing.

Appendix C

Terminology and Acronyms

Terms used in this paper, may vary geographically, and may be superseded over time. The list below is intended to summarise Marsh's definition of each term, and common acronyms.

Temporary repair, an engineered or non-engineered repair installed on a piping system to seal a leak or to prevent an anticipated leak. The components used are in addition to the existing equipment, as opposed to replacing the damaged equipment with new components.

Permanent repair, any repair that has been designed, manufactured and installed by competent engineers in compliance with a recognised industry code. The repair must have been assessed, reviewed and approved under a Management of Change (MOC). The prefix 'permanent', means that the up-front engineering, inspection, operations, maintenance and management review has considered all aspects of accepting the installation as a permanent feature. There must be a strong technical basis to allow the repair to remain in place for the same duration as the parent pipe or equipment.

Defined life repair, is intended, by Marsh, to replace "permanent repair". The use of the term permanent is debated, as almost all equipment will deteriorate in service over time, meaning it will require replacement or decommissioning once it reaches its design life. The parent equipment that the repair has been installed on can reach its design life before the repair, for example, a mechanical clamp repair, not exposed to internal process fluid, while being maintained externally, while the parent pipe continues to degrade internally. The duration of a design life must consider TA cycles, normal and upset operations, transient operations and idle periods.

Like-for-like repair, replacing deteriorated equipment with new equipment of the same design and metallurgy (often to modern metallurgical standards). For example, the version history of the specification for carbon steel, [ASTM 106 Grade B](#) summarizes seventeen preceding specifications, each with modifications to material properties. The grade procured today will typically conform to modern specifications unless specified. This constitutes a MOC but can be pre-engineered by updating company pipe specifications/pipe classes.

Acronyms

[ASME](#), American Society of Mechanical Engineers

[ASTM](#), ASTM International, formerly known as American Society for Testing and Materials

[EEMUA](#), Engineering Equipment and Materials Users Association

LMA, Lloyd's Market Association

MOC, Management of change

PCC, Post-construction code

PWHT, Post-weld heat treatment

TA, Turnaround (planned plant outage to facilitate inspection and maintenance activities)



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