Use of "3-sided PFP" Protection of Steel Beams in Petrochemical /Oil & Gas Industries

This Position Paper was developed by PFPNet membership, and approved by the PFPNet Steering Committee, and provides PFPNet's position on the use of "3-sided PFP" protection.

POSITION STATEMENT

It is the position of PFPNet, and its members, that the practice of leaving top surfaces of structural beams unprotected when exposed to the heat of a fire, will result in the member rapidly exceeding temperatures detailed in design codes and industry guidance with the potential for premature structural failure.

*"3-sided PFP" **should not** be used with the assumption that it is a correct detail that provides suitable fire protection, regardless of the situation in which it is deployed. In addition, it **should not** be used with the assumption that compensating for the lack of the material on the top surface with additional PFP on other faces provides a safe design. This guidance applies to all forms and brands of PFP.*

A PFP design leaving the top surface of a beam unprotected may be adopted but requires an engineering demonstration that the solution is suitable for the situation in which it is used. This should demonstrate that heat transfer into the beam is sufficiently restricted in the design fire scenarios to prevent a premature structural failure. Engineering demonstration using modelling of the structural fire response should be supported by evidence from testing. The assessment should consider the fire type, size, duration, and location relative to the beam, any loading of the beam, its dimensions and geometry, the influence of any secondary structural steel, pipe work or grating that might offer restraint to the beam, and the heat transfer properties of the PFP.

If "3-sided PFP" is shown by the engineering assessment to be a credible mitigation option that will provide the required structural performance, then any PFP system should be detailed to ensure that it retains its integrity in a 3-sided configuration due to rapid heating of the steel and does not detach at free edges.

If the engineering assessment shows that "3-sided PFP" will not provide the required structural performance, but that PFP is required, then design details are available that allow for full "4-sided PFP" protection to be applied, and these details can be incorporated if they are considered early enough in the design phase. PFP suppliers and facilities' designers can assist with this detailing.

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PFPNet 3-Sided Protection Review Group

This position statement was prepared by Dr Enrique Munoz-Garcia of MMI Thornton Tomasetti and reviewed and commented on by representatives from the following organisations:

Carboline, Gexcon, Hempel, International Paint, Isolatek, JGC, Jotun, MMI Thornton Tomasetti, PFPNet, PFP Specialists, PPG, Promat, Sherwin Williams, Technip FMC, UL, and WarringtonFire.

BACKGROUND AND FURTHER INFORMATION

Description

Passive fire protection (PFP) coatings are used in the petrochemical/oil and gas industries as a method to avoid or delay collapse of steel structures in onshore and offshore installations.

Because the oil and gas industry was predominantly focused on protecting against pool fires burning at ground level, it became normal and accepted practice to leave the top flanges of PFP-protected beams uncoated on the assumption that the level of direct heating at the top flange was low. This type of protection has become known as "3-sided protection". There are practical reasons for this, such as to allow for the installation of grating and pipe supports on top of the unprotected flange, so that they seat correctly onto bare steel rather than onto PFP.

3-sided protection in these industrial situations is different to 3-sided protection in the building industry. Here the top flange usually supports a floor, such as a concrete slab, and the presence of the floor provides fire protection to the top flange of the beam. 3-sided protection may have been adopted for industrial situations because of a misunderstanding of this built environment detail. The top flange of a 3-sided protected beam in an industrial application is usually fully exposed, therefore allowing for direct or indirect fire impingement, depending on the size, location and type of the fire.

What Happens in a Fire?

If exposed to fire, the unprotected surface of the top flange rapidly heats up with heat conducted down into the structural section. This leads to non-uniform temperature distribution through the depth of the section as shown in Figure 1. As steel heats up, it reaches a temperature at which its strength starts to reduce. When the temperature distribution is non-uniform, the loss of strength is also non-uniform, leading to instability. The result is that the reduction in strength of the steel, combined with any instability reduces the load carrying capacity of the structural member.

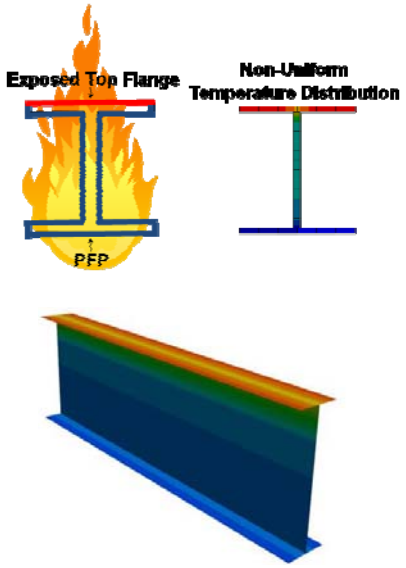

Figure 1: Non-Uniform Temperature Distribution due to Three-Sided Fire Protection

Evidence

Several studies of partially protected beams [1],[2],[3],[4],[5] have demonstrated that 3-sided PFP can ***accelerate*** bending and stability failures (such as local buckling and lateral torsional buckling), due to the non-uniform thermal gradient developed through the cross section. Experimental tests have confirmed this, and in one study it was found that beams capable of withstanding 2-hours of engulfing hydrocarbon fire when fully protected on all sides, reached failure in less than 15-minutes when protected using PFP as 3-sided protection [6].

One observation [6] is that the fire rating and PFP thickness play a small role in the failure mode and time to failure.

It has been practice to take PFP material thickness calculated for full (4-sided) protection and distribute that volume of material around just 3-sides, the opinion being that the extra thickness on the 3-

sides provides extra protection and compensates for the top surface being unprotected. These "3-sided" thicknesses are unvalidated. It has also been practice to use material thicknesses determined from tests where a slab or other flooring system has shielded the top flange during testing. In general, applying results from testing in a given configuration to another configuration is an incorrect justification.

Where heat enters the top flange, the thickness of PFP applied to the other sides will not stop this action and may make the situation worse by retaining more heat in the section and increasing the non-uniformity of the temperature profile within the cross-section.

However, and very importantly, anecdotal evidence from observations following real fires has shown that the failure of the beams predicted by analysis and test is not always observed in real situations. This discrepancy suggests that there are a range of factors that will control whether a beam survives a real fire without collapsing, but it is not necessarily true that 3-sided PFP protection is the reason for this survival as basic heat transfer and engineering calculations do not support this behaviour.

Preventing Structural Collapse in a Fire is an Engineering Issue, not a PFP Coatings Issue

There is no definitive design guidance or standard that specifies how to analyse and design partially coated beams.

One frequently referenced standard that contains statements about this topic is API 2218 3rd Edition [7], Annex D (informative) Section 5 which is reproduced below:

*"**Question:** Does the entire surface of horizontal beams need to be fireproofed to protect against a ground fire?*

***Answer:** Opinions vary based on scenario. For the upper most beams on the perimeter of the envelope the top side may be uncoated because pipes have to rest and slide across. Thus, fireproofing may not be specified for the top flange of beams where a fire scenario exposure is heat radiation (not flame contact) from a fire below the beam. Note that unfireproofed metal can conduct heat into a fireproofed portion…….. ……Fireproofing experts recommend that only fire engineered solutions should allow for not fireproofing all sides of the beams."*

Whilst this advice is informative, it does not actually propose that the 3-sided PFP detail is widely applicable to every situation. It does, however, very clearly highlight the importance of performing an engineering assessment of beams that are load-bearing and exposed to fire in order to understand their response during a fire scenario, rather than specifying 3-sided PFP protection as an accepted detail assuming it will automatically mitigate against collapse for all situations.

In some instance verification/certification bodies require demonstration (and possibly fire test certificates) that 3-sided protection is an adequate protection against the design fire scenarios.

Factors that can influence failure of a beam in a fire can include beam size, section factor (A/V), connection details, restraint provided by secondary steelwork, services, pipes and gratings, type of fire, fire duration, location of fire with respect to the structure (engulfing/non-engulfing, received heat flux, etc – derived from validated fire modelling methods) or any combination of these factors.

Reference [4] lists some practical solutions that can be implemented to delay/avoid the failure of the beams exposed to fire. Correctly detailed PFP is an effective mitigation option in preventing failure of beams in fire. Alternatives to a 3-sided PFP design would be a fully coated section, where supporting details are used to raise any items that would have been seated on the top flange above the installed PFP, or the specification and design of local PFP that protects areas of exposed top flange.

What is certain is that early recognition of the need for PFP in a project means that an effective PFP mitigation can be included using practical solutions.

References

[1] G. K. Castle and G. G. Castle, "*Effect of fireproofing design on thermal performance of horizontal members with top flange exposed*" Plant/Operations Progress, Volume 6, Issue 4, pages 193–198, October 1987.

[2] Hunter Smith, Yavuz Ayhan, Ali Sari, "*Fire Assessment of Steel Beam Members with Partial Passive Fire Protection Coverage*", ASME 2012 International Mechanical Engineering Congress and Exposition, Volume 8: Mechanics of Solids, Structures and Fluids, Houston, Texas, USA, November 9–15, 2012.

[3] H. Smith, A. Sari, Y. Ayhan, "*Advanced Analysis Methods for Complex Structural Fire Assessment Problems*", Offshore Technology Conference 2013. Houston, Texas, USA, 6-9 May 2013

[4] E. Munoz-Garcia, "Analysis and Design Challenges and Solutions of 3-Sided Passive Fire Protection (PFP) on Steel Beam Decks for Offshore Installations", OTC Asia 2016, Kuala Lumpur Malaysia, 25th March 2016.

[5] R. Sun, E. Munoz-Garcia, "Three-Sided Partial Protection for Horizontal Beams on Offshore Installations: Problem, Design and Solutions", 2nd International Conference on Structural Safety Under Fire and Blast Loading CONFAB 2017, London, United Kingdom, September 10-12, 2017.

[6] [Muhammad Imran, "*Behavioural Study of Unrestrained Three-Sided Protected Steel Beam Subjected to Hydrocarbon Fire*", PhD Thesis, Information Resource Centre (IRC) of Universiti Teknologi PETRONAS (UTP), Perak, Malaysia, 2019.

[7] API 2218, Fireproofing Practices in Petroleum and Petrochemical Processing Plants, THIRD EDITION, JULY 2013.