Looking Beyond Relief System Design Standards

M. Reilly & T. Craddock

Introduction

A correctly designed relief system is key to safe plant design and operation, ensuring the ability to handle any potential process upset and mitigate the associated hazards. However over time the application of relief standards and design guidelines has narrowed often leading to the wider view on the hazardous events to be neglected.

Therefore it is important to look beyond a standard approach to ensure all relief cases are considered thoroughly as part of the overall design and those deemed ‘secondary’ are not later ignored / discounted. By excluding secondary relief cases the design developed for the ‘sizing’ case may in fact not be fit for purpose, therefore rendering the current design redundant for the secondary sizing cases. Current relief standards do not require you to develop design for secondary cases, as they are focused on ensuring the worse ‘sizing’ case has been designed for; however the frequency of the other events may be more likely. An example of this is, often vessels may be sized for fire, however, how does the fire case frequency compare to the secondary case of blocked outlet?

Similarly the sizing methods presented in the relief standards are often applied to the incorrect scenario or the process is not challenged. This can lead to potentially under estimating the required relief rate or sizing the system based on an unrealistic scenario. This is prevalent as more and more operations within the oil & gas industry operate (or have the potential to) within the supercritical (dense) phase. However the risk can be much simpler; is the current relief sizing method applied to the hazardous event actually applicable for this case? Is the design the best fit process?

Change will nearly always happen during the life cycle of a project and is normally managed, controlled, communicated & implemented as part of the design. However as with design, relief standards, guideline & procedures are also revised. The control of change with regard to such documentation is generally not well managed, leading to a potentially improper / uncompliant relief design at the end of the project. Is there a well-documented process to handle change in relief design standards or guidelines in your environment? How has the change impacted the current design?

All of the above threats within relief design can be mitigated by challenging relief design and the basis on which it was designed throughout the project life cycle. Similar to the hazard assessment and identification process that is started before relief design, relief design should be considered as a live process which is revised as design develops. A single ‘one fits all’ approach should not be applied to relief design and each case should be considered in its own merit.

The sections below present the issues discussed above and our experiences with them as part of detailed relief design. The purpose of this paper is to challenge how your relief design standards & guidelines are implemented and question whether during design you consider all the potential scenarios for the relief design.

Determining Relief Basis & Sizing for Secondary Relief Cases

Relief design focuses on the design of safety systems to handle the worst case scenario. This, as a result, often draws the focus of design to be narrowed to a single ‘sizing’ case, and the secondary cases are not pursued further or carried through to final design. This poses a risk, as the proposed design may not be able to handle the secondary relief case. Similarly the demand frequency of the secondary cases may be significantly greater than the primary ‘sizing’ case, and therefore the secondary case should be carried through the design to ensure the system is fit for purpose.

This issue was recently highlighted during an as-building exercise of relief design calculations, to ensure the installed relief valves and associated pipework offered the required protection, as part of a new gas plant for a Client. It was identified during the task that the original project relief sizing basis (relief valve sizing calculations & line sizing) omitted the secondary cases. In some instances relief inlet / outlet pipework pressure losses from these omitted cases were found to exceed the design standard limits.

Two Phase Flow

One of the issues identified was a separator (liquid knock out drum) which had been correctly designed for the governing relief case, fire; however the blocked outlet secondary relief case had not been carried through in design. This on further calculation highlighted that the relief system pipework had been designed for vapour relief only; however, during a blocked-outlet event the relieving fluid was liquid which would flash across the relief valve resulting in two-phase flow. The two phase relief velocity was also found to be in excess of the maximum allowable velocity as per ISO 13703. To solve this issue the outlet relief pipework required to be increased from 8” to 10”, and properly supported & braced to handle the two-phase flow which could result.

Wetted vs Unwetted Fire Cases

During a validation exercise, it was identified that a relief valve and pipework had been correctly sized for the governing relief case, Unwetted Fire, on a new Regen Knock-out drum. However the calculation had not considered the impact of the wetted fire case on the relief pipework. The required relief area was significantly smaller for the wetted compared to the unwetted, scaling the relief flow for the rated flow resulted in a similar rated flow to that of the unwetted case. However the physical properties were significantly different, therefore this resulted in larger inlet pressure losses. The table below summarises the results found;

Table 1 - Wetted vs Unwetted Fire Case Relief Design Comparison

Scenario	Required Relief Area (in^2)	Rated Flow (kg/h)	Inlet Losses based on 3" Inlet
Unwetted Fire	0.350	8,676	2%
Wetted Fire	0.045	8,009	>4%

Therefore to reduce the relief valve inlet pressure losses to below 3% of the set-pressure (as per ISO 4126), the 3" pipework would need to be replaced with 4" pipework with associated losses of <1%. This had an impact on the overall plant design to accommodate the larger pipework.

Rated Flow & Vendor Calculations

The following example highlights the importance of considering the wider relief picture as part of design and ensuring a complete design basis is established. The initial design of a PSV to protect a methanol storage vessel had identified a 'G' orifice was required, with a corresponding rated flow of 2999 kg/h. Inlet pipework was appropriately sized at 3".

However as the plant design progressed, the relief valve became part of a vendor package. The vendor selected an 'H' orifice to meet a greater required flow rate as a result of a capacity change within the package, and used a larger superimposed backpressure assumption (50% of PSV set pressure). The inlet pipework losses were found to be marginally below 3% of set pressure for the new rated flow of 3958 kg/h.

However at this stage, the high superimposed backpressure assumption was not challenged. The 50% of set pressure assumption was based on a pool fire in the methanol storage area, in combination with plant blow down at full peak flow. This event is unlikely as it would require a double jeopardy event to occur.

Revising the calculation for a more realistic super imposed backpressure of ~20% (based on normal LP flare header pressure) resulted in a rated flow of 4681 kg/h for the selected orifice size, which increased the inlet pipework losses to >4% and this required the replacement of the 3" inlet pipework with 4" pipework to lower inlet losses accordingly (1% inlet losses).

This case the highlights the need for relief basis of design to be clearly understood and any change in basis is correctly considered & challenged. By not defining it clearly in the early design stage, the vendor sized the relief valve based on the worst case flare header / super imposed back pressure, however on review this was deemed an improbable case, and sizing the valve based on normal flare back pressure would be a more suitable method. As a result of the larger orifice area selected by the vendor, the previously sized inlet pipework was not suitable for the increased rated flows and the pressure losses exceeded the limit as set by ISO 4126.

Suitability of Sizing Methods

Supercritical relief

Current relief standards do not present the relief of supercritical fluids in an easy and coherent manner. As a result neither does industry in general. Identification of supercritical relief scenarios is only the start of the challenge as discussed in the previous section. If you delve into relief standards, the standard vapour relief sizing methods are only applicable over a compressibility range of 0.8 – 1.1 (based on ideal gas equations) and supercritical fluids generally fall out with this range. However to apply liquid sizing equations would also be incorrect, as this would result in a far greater than required relief area. Supercritical fluids lie somewhere between either ends of these relief sizing methods.

Similarly the heat input for fire cases cannot be easily determined based on the current standards, as the surface of the supercritical fluid vessel being relieved is neither unwetted nor wetted. The mechanism for supercritical fluid relief is fluid expansion therefore to best determine the required relief area, a direct integration of the Isentropic Nozzle flow (HEM Method) should be used. Additionally the Leung-Omega method as noted in API 520 Part 1 can be used to size for supercritical relief.

Due to the lack of clarity in current relief standards, the relief design is often implemented incorrectly. An example of this is during the sizing of a compression train inter stage relief for blocked outlet, three different methods were used to size the relief valve;

Table 2 - Supercritical Relief Design Summary

Scenario	**Summary of Required Areas**			
	Vapour Area (in^2)	**HEM Area (in^2)**	**Leung-Omega Area (in^2)**	**Installed Area (in^2)**
Blocked Outlet (Supercritical)	0.101	0.136	0.153	0.196

As expected the standard vapour relief sizing method underestimates the relief requirements as the relieving fluid (z = 0.475) is not within the ideal gas range of >0.8 & <1.1. The relief valve inlet & outlet pipework was sized based on the rated flow associated with the HEM method, however during a review of the relief valve it was noted that the vendor rated flow was greater than the sizing basis used for the relief lines, which resulted in the Mach limit of 0.8 being exceeded for the current design pipework. The table below shows the difference in rated flows between sizing methods and vendor calculated rated flow;

Table 3 - Supercritical Relief Rated Flow Comparison for Different Methods

Scenario	**Summary of Rated Flows**			
	Vapour Rated Flow (kg/hr)	**HEM Rated Flow (kg/hr)**	**Leung-Omega Rated Flow (kg/hr)**	**Vendor Quoted Rated Flow (kg/hr)**
Blocked Outlet (Supercritical)	14,903	11,072	9,836	12,919

After liaison with the vendor the ~16% difference in rated flow was identified as a result of the vendor sizing the PSV based on ideal gas equations and not considering the fact at relief the fluid will be supercritical. The vendor then reassessed the relief valve for supercritical relief and their revised results matched those calculated as part of our design. This satisfied the Client and ourselves that the current design based on the HEM method was fit for purpose.

Another example of the misapplication of supercritical relief was identified where the relief from a Feed/Product heat exchanger would be supercritical on the high pressure side of the exchanger, as the relief set-pressure was above the critical pressure. However, the fluid temperature would not be critical until the critical temperature of 188°C was reached; the initial relieving fluid temperature was 65°C. At this stage in the design the unwetted fire sizing method as per ISO 23251 was applied and resulted in a relief area of 0.035in^2, however this is invalid as the relieving fluid is still a liquid. The actual relief case for fire will in fact initially be liquid relief and as the fluid temperature is increased to critical temperature, the fluid will become supercritical and the expansion is far more significant.

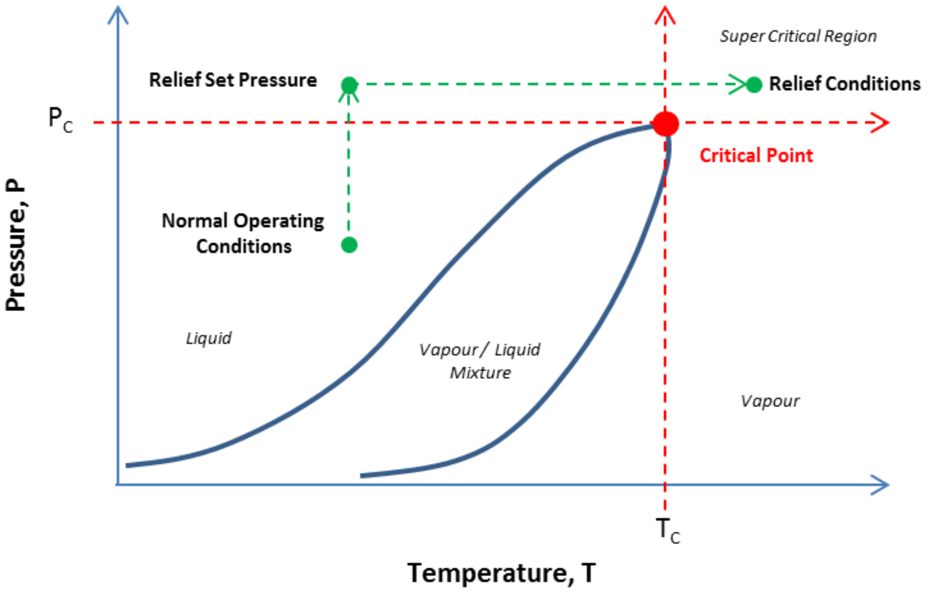

Figure 1 - Pseudo Phase Envelope with Relief Conditions overlaid

The revised required relief area for the supercritical relief was calculated as 0.046in^2. Not only had the change in philosophy affected the required relief area but it also impacted the relief outlet pipework sizing, as at the lower temperature, the outlet pipework had been sized on two-phase flow due to the flashing of the liquid across the relief valve. However at the elevated conditions, the relief flow in the outlet pipework is a single phase gas flow, which resulted in a Mach number in excess of 0.8 being calculated. This required the relief pipework to be assessed and replaced.

The above examples highlight the potential pitfalls of sizing supercritical relief, as using ideal gas equations will potentially under estimate the required relief area & overestimate the relief inlet / outlet pipework size. In this instance there was no requirement to change out the selected valve orifice only pipework modifications, however the under estimation of relief area could easily lead to a complete redesign of the relief network from pipework, valves & relief header if not correctly assessed in the first instance.

New Technology

New technology is another process within which the suitability of sizing methods must be considered. Relief design standards and guidelines cannot and unlikely ever will consider every possible case and as such engineering judgment must be applied in their implementation. However faced with a new or novel technology, how are these standards implemented?

An example of this is an implementation of a new import gas heat exchanger for an offshore installation. During the initial design, it was identified that a shell & tube design would be the most suitable due to the process conditions. However, it was identified that significant space saving could be achieved if the design was changed to a compact design. Technology such as printed circuit exchangers were discounted due to concerns that they could become blocked, as experience had shown the heating medium system had previously been contaminated.

The technology chosen was a compact shell & plate design; however the differential pressure between the two sides of the heater was significantly higher than the manufacturer's experience. The sketch below shows the system;

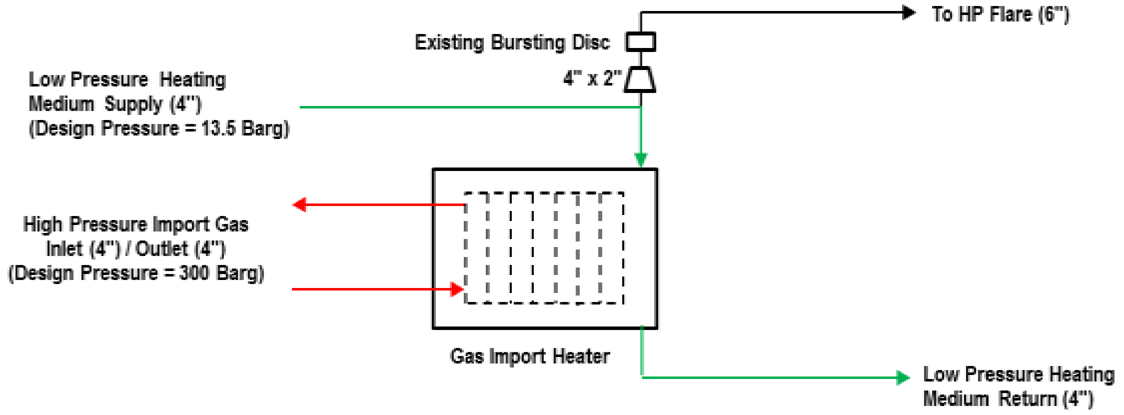

Figure 2 – Initial Relief Arrangement to protect Heat Exchanger

To give confidence in the design, two trial units were fabricated and subjected to burst tests, with both bursting at pressures circa 700 barg - which was three times the required design pressure of 200 barg.

For shell and tube heat exchangers, ISO 23251 provides guidance on the size of failure that should be used for sizing relief devices to protect the low pressure side from a burst tube scenario; however it does not provide any guidance on compact heat exchanger design. At the time of design, the relief system was sized on the vendors maximum credible failure size of 1mm by 10mm (10mm^2) based on a plate port weld failure (Refer to Figure 3).

However during offshore leak testing, a failure of the plate weld occurred leading to high pressure gas passing into the low pressure heating medium side. On inspection the size of failure was found to be significantly larger that the design basis (circa four times the original sizing method of 10mm^2). Therefore the relief system was not designed correctly to handle such a failure. The sizing basis therefore had to be reconsidered, however what basis could be selected when there is no guidance / documentation available?

On review, it was decided to implement the approach used for shell and tube exchangers where the guillotine failure of a single tube is considered when determining the burst tube relief loads. The largest possible flow area & resulting relief flow from a single plate failure assumes the failure occurs around both sides of the plate port connection.

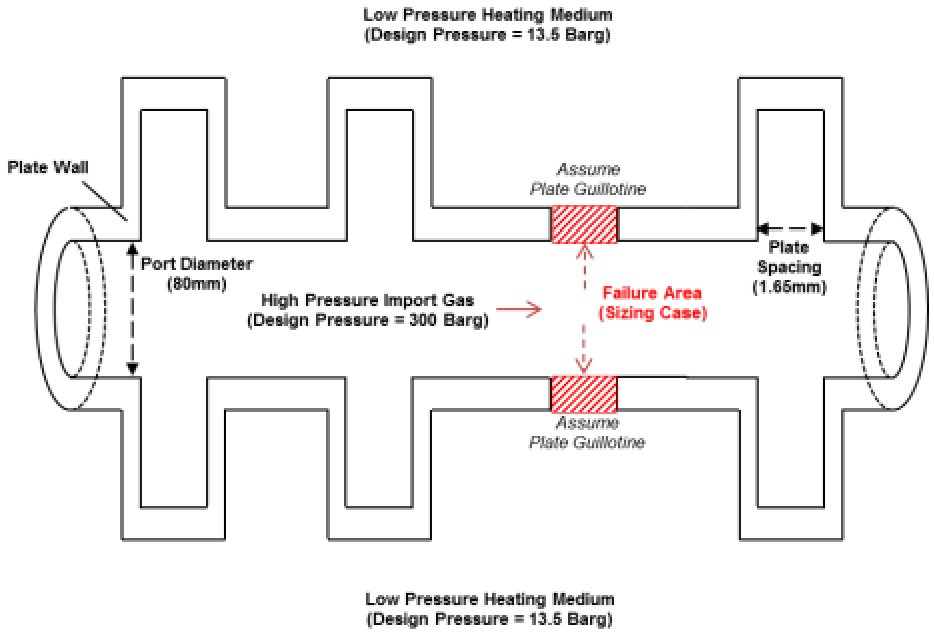

Figure 3 - Cross-sectional representation of Plate & Failure Case

As shown above, this significantly increases the failure size to ~830mm^2 assuming that both plate gas inlet and outlet weld failures. This was around eighty-three times the original sizing basis. The corresponding relief flow was found to be more than twice the design flow for the heat exchanger.

To ensure the system could adequately handle such relief flows, the relief arrangement had to be completely redesigned. Had there not been sufficient flare header capacity (legacy from the original shell and tube design) then the flare header would also have to be redesigned.

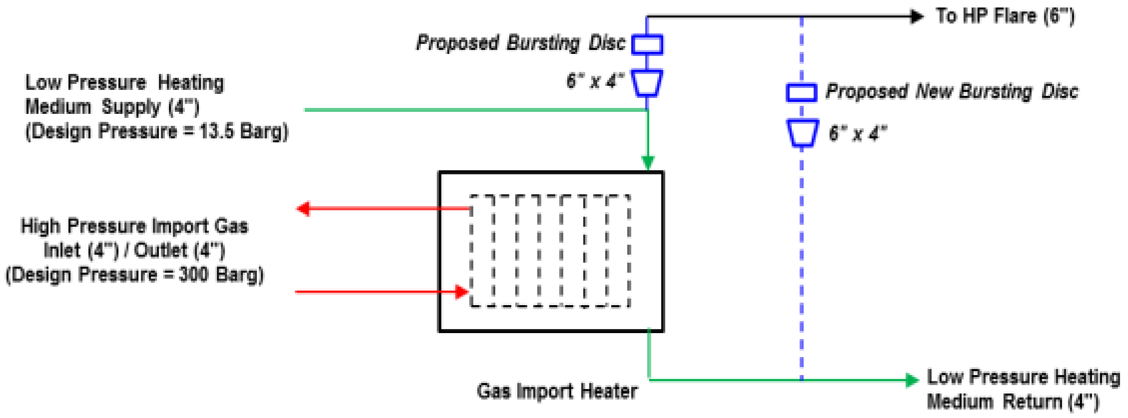

Figure 4 - Proposed Solution to Protect for New Relief Case

The case of this new technology heat exchanger shows that with any design, where there is no relief guidance or insufficient information available, a robust complete approach to relief design must be considered with suitable engineering judgment applied. The consequences of such a failure during actual operation could have been potentially catastrophic.

Change in Design Standards & Guidelines

Change in design happens throughout a project lifecycle. Similarly, design standards, guidelines & regulations are continuously revised. Within industry these changes are often not managed effectively leading to conflicts & redesign further through a project lifecycle. An example of this and the impact on relief design was the change in Client's standards with respect to reverse flow through check valves;

Compressor Reverse Flow

The control and design of HP / LP interface protection is critical to safe design & operation of a plant. This is especially relevant in the instance of reverse flow cases, as the associated relief rates can be significant.

During the installation of a new gas export compression train, it was identified that there could be reverse flow from the pipeline which the second stage export compressors fed. This could lead to overpressure of the downstream system via failure of the compressor recycle control valve which ties into the 1st stage compression system. To limit the relief load, two dissimilar non-return valves had been installed. A sketch of the system is shown below;

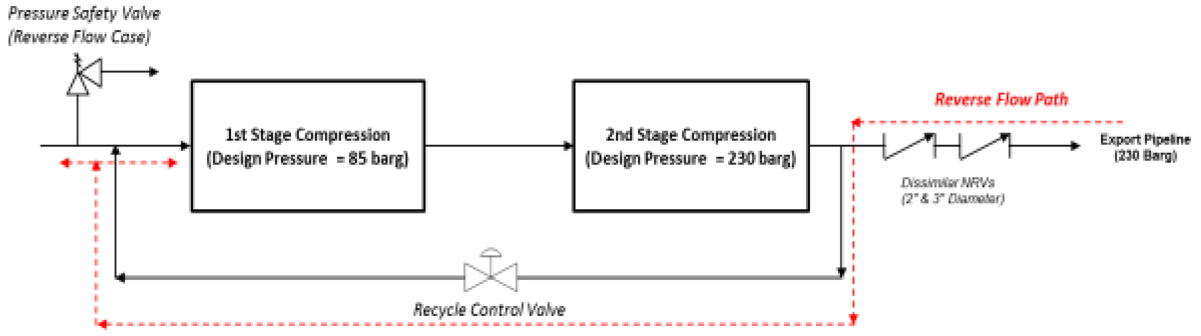

Figure 5 - Simplified PFD highlight Reverse Flow Case from Export Pipeline

The original relief sizing basis was determined based on reverse flow through a single orifice with a diameter equal to 10% of the diameter of the largest non-return valve (3”), which was consistent with both international standard (ISO 23251) and Client standards. This resulted in a required relief area of 0.299in^2 for which the relief valves had an installed area of 0.307in^2.

However as the design progressed, the Client relief valve standards changed and reverse flow leakage should be based on a flow area equal to 10% of the flow area of the largest check valve as the reliability of the two check valves in series could not be ensured. This change results in a relief flow 10 times greater than the original sizing basis. This change not only affected the size of the relief valve but also the associated outlet pipework size.

The table below show the impact on required relief valve area and flare header size based on these changes.

Table 4 - Compressor Relief Area Comparison Based on Check Valve Area Sizing Method

Relief Design Case	Required Relief Area (in^2)	%Increase in Relief Area	Minimum Relief Valve Pipework Size (in)	
			Inlet	Outlet
Installed	0.307	-	2	4
Case 1 – 10% 3” NRV Diameter	0.299	-	2	4
Case 2 – 10% 2” NRV Area	1.283	318%	4	8
Case 3 – 10% 3” NRV Area	2.999	877%	6	10
Case 4 – Control Valve	1.873	510%	4	8

The change in relief sizing philosophy in this instance significantly increased the relief requirement to comply with the new standard. By designing the system to 10% of the total check valve flow area, in the case of the 3” non-return valve, resulted in an area which is greater than the actual control valves could pass via reverse flow.

As the system had already been purchased & installed but not commissioned when this discrepancy was identified, the Client is currently completing risk based assessments to determine the impact on operation and extent of redesign (if required). This is due to the potential magnitude of rework involved in replacing relief valves, associated pipework & sections of the flare header pipework.

This example demonstrates how a perceived relatively small standard change in standards can lead to large change in relief design. If this change is not managed effectively then such change can result in not only significant redesign but potentially significant plant modifications to ensure the design meets the standards.

Conclusion

The examples discussed highlight that all relief scenarios and associated design should be considered on their individual merit. Our own experience shows that direct application of design standards can lead to a flawed relief design. Each relief case should be challenged to ensure; correct basis identified, sizing method used is fit for purpose and application of current standards.

- Secondary relief cases may not be the worst case from an over-pressure point of view, however they can be the limiting factor in design especially with respect to inlet & outlet pipework. Frequency of secondary cases may be significantly greater than that of the sizing case. Therefore they cannot and should not be ignored from the sizing basis.
- Relief is a vast topic. There is not one method that suits all cases, therefore the basis for any relief calculation must be clearly defined and understood. The limits to each sizing method should be considered in design development i.e. Supercritical relief fluids properties generally are far removed from the ideal gas sizing method, which is often wrongly implemented for such cases. Similarly there may not always be guidance on the exact method to use, as is the case for new technology, therefore informed engineering judgement should be applied to develop a robust design.
- Design changes and develops as part of a project’s lifecycle. So do design standards, procedures & guidelines; however these changes are not handled as effectively as design change. What may have been acceptable during early design may no longer be valid or require some form of exception. The earlier such change can be captured, the greater the potential to minimise redesign & cost, whilst ensuring a robust design.

Relief design should not be an activity that is viewed as being completed as part of the early design process and then never revised or reassessed. It is important that sufficient effort is taken during the initial design to look beyond the standards and perform a comprehensive review of the relief design. Equally it is just as important to review any relief design later on in the project to ensure its validity, as the design has developed.