CANADA
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FURTHER WEIGHT AND COST SAVING

ON MODULARIZED OIL AND GAS INSTALLATIONS VIA A NEW, 4TH TYPE OF BLAST AND FIRE RESISTANT WALLS AND A COMPREHENSIVE DECISION MAKING MODEL

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Abstract

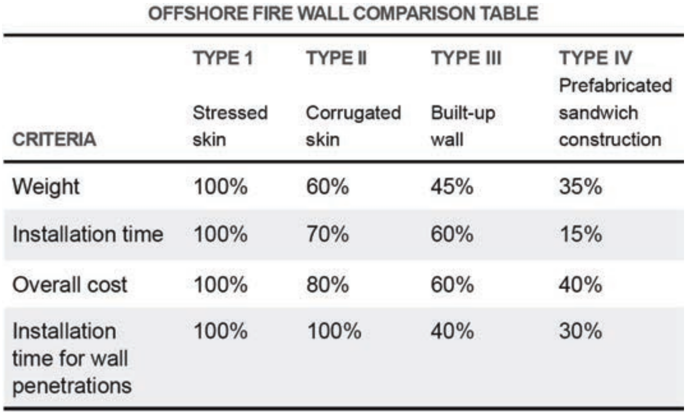
This paper presents an overview of 50 years of development of blast and fire resistant walls for modules and introduces the fourth generation or "Type" of walls. This thoroughly tested and certified 4th Type was developed as a response to the continuous quest to further optimise the cost and weight of modules, thus allowing operators and designers to accommodate more equipment and higher field yield.

Inductive research indicates that the selection of a blast and fire resistant wall design amongst the available Types is very often biased and predominantly based on past experience. As such, the traditionally selected option has been a monocoque structural design incorporating load bearing walls instead of framed construction designs with non-load bearing infill walls. This bias can lead to sub-optimal design and execution of modules.

This paper reflects on 4 Types of offshore blast and fire walls. From the 1st Type, derived from the shipbuilding industry up to the 4th Type, initially used on recent offshore wind HVDC transformer platforms and more recently also on the oil and gas platforms as a response to the continuous need to reduce weight and improve on safety. This 4th Type, with a weight of just 25 kg/m2, is certified as capable of withstanding up to 2 hour hydrocarbon fires and has been tested with a considerable free span.

In this paper, all 4 Types of walls are assessed against a limited series of hard and soft performance criteria, according to a decision making model which can be used to select the fittest-for-purpose Type of wall system. This model includes the distinction between internal fire walls, external fire walls and external blast and fire walls.

A comparison of the 4 Types based on core criteria is shown in Table 1.



OFFSHORE FIRE WALL COMPARISON TABLE

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Weight	100%	60%	45%	35%
Installation time	100%	70%	60%	15%
Overall cost	100%	80%	60%	40%
Installation time for wall penetrations	100%	100%	40%	30%

Table 1: Offshore fire wall comparison table - core criteria

It is expected that the developed decision making model will be further enhanced in the future based on feedback from offshore architects and engineers.

This paper is concluded by a section providing examples in which the model is used to optimise wall design decisions, based on various realistic scenarios. Also, practical fixing details and other useful design recommendations are provided for the 4th wall Type.

1. Introduction

As the current oil price seems to be relatively stable between US$ 40 and US$ 60 per barrel, operators and EPC contractors are keen to lower the trigger point of their projects comfortably close to the lower side of recent oil prices. In order to achieve this, EPC's and operators embrace MSI, Modularization, Standardisation and Innovation. [1] [2] [3]

Although the oil and gas industry still shows risk averse behaviour, in order to further lower the cost price per barrel now the industry is welcoming low cost solutions that drive CAPEX and OPEX down, whilst keeping safety standards to the maximum level.

The intention of this paper is to make the professionals keen to consider blast and fire wall designs for oil and gas installations without bias with an objective viewpoint, allowing them to further optimise the design for additional weight and cost savings.

1.1 The start of offshore drilling

Offshore drilling for oil began off the coast of Summerfield, California in 1896. Closely resembling walkboards in appearance, rows of narrow wooden piers extended up to 1,350 feet from the shoreline. By 1947, when Kerr-McGee oil Industries drilled the first production well beyond the sight of land, firms increasingly chose steel over wooden drilling structures, recognising the metal's greater structural capabilities for rigs and its lower costs over the life of the well [4]. At that time, rigs were designed by shipbuilders and therefore built like monocoque structures as shown in Figures 2 to 4.

It took a while for Naval architects to pick-up on the container design (see Figures 5 to 7), which was standardised by Malcom McLean. This corrugated design had a positive impact on weight for offshore platforms.

Both Types of walls are currently still in use. However, in the 1970's companies started to experiment with lighter weight cladding constructions in order to reduce weight and lower production and installation costs (see Figures 8 to 10). Fire resistant cladding panels have been in use onshore since the 1980's. These panels comprise 2 light gauge metal panels with insulation in the middle and are assembled on site. Technology that has recently become available now enables the fabrication of fully prefabricated and certified sandwich panels which can be delivered to site and installed in one single operation.

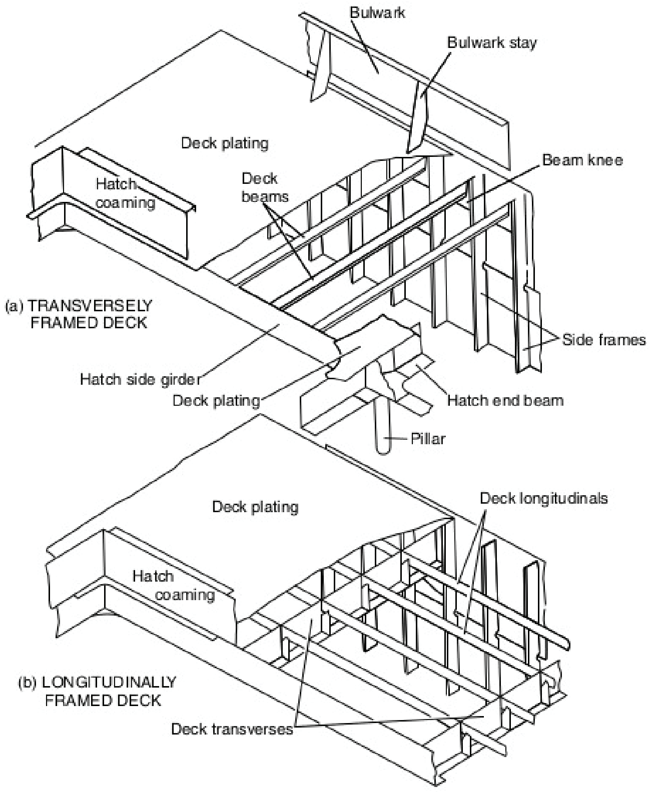


FIGURE 19.2 Deck construction

Figure 2: Type I monocoque structure

Figure 3: Early Type I fire wall

Figure 4: Type I offshore installation-museum

Figure 5: Loading of 1st containers

Figure 6: Stainless steel Type II walls during construction

Figure 7: MS Type II walls in use (MS = mild steel)

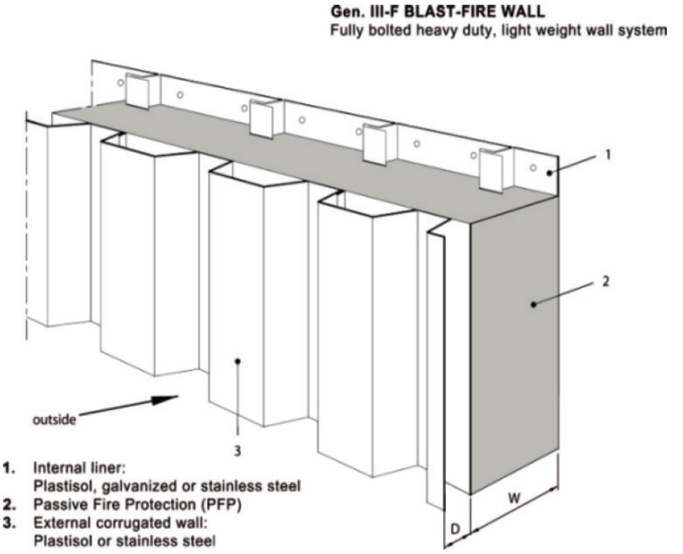


Figure 8: 3-D drawing of Type III built-up wall

Figure 9: Type III wall under construction

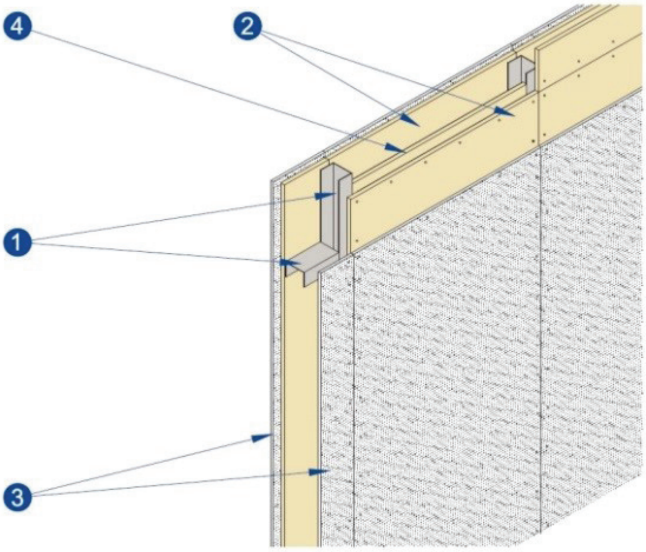


Figure 10: Type III built-up wall

1.2 Safety

Shortly after the Piper Alpha disaster in 1988, offshore safety regulations were tightened and regulations relating to fire resistance tests became more stringent. Different types of construction elements had to be tested separately. The fact is that the strength of steel diminishes as the temperature increases. At temperatures above 800 degrees Celsius, steel loses around 90 percent of its strength as shown in Figure 11.

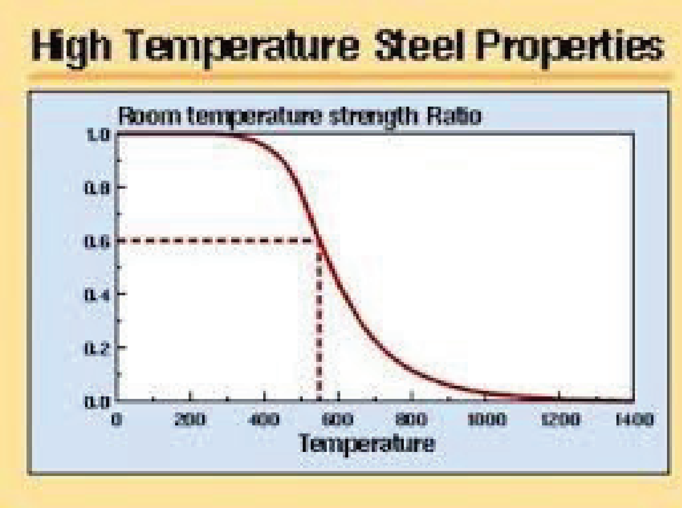


Figure 11: Strength of steel as a function of temperature

Piper Alpha and more recently the Deepwater Horizon disaster demonstrated that steel indeed buckles when subjected to large hydrocarbon fires, and even more so when structures are load-bearing (see Figures 12 and 13). If walls are used to support the structure above them or heavy equipment, these might buckle within the time defined by their fire rating.

Figure 12: Column head (failure at 5000C)

Figure 13: Abkatun A Pemex platform April 1 2015 deadly fire

1.3 Premature buckling

There are basically 2 ways to prevent premature buckling from happening. The first is to make sure that in the event of a fire, the imposed loads are immediately released by using fixings that rapidly fail at the beginning of a fire (e.g. at around 200˚C) for instance.

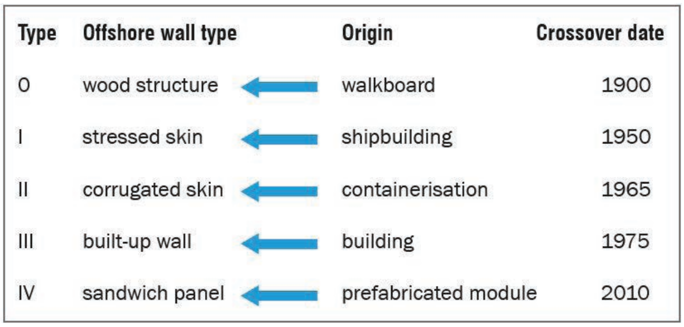
Another alternative is to ensure that the temperature of the load bearing steel will be well below the limit defined by the required load bearing capacity. This implies that the steel needs to be isolated from the expected fire side.

There is also an obvious third option: the use of non-load bearing walls. This ensures that the response of the walls during laboratory tests is as close as possible to what it would be when subjected to actual fires. Loads from equipment items hung on the walls can be transferred back to the wall support structure and to the decks, thus ensuring that the wall itself will not buckle in the event of a fire and will keep the “cold side” safe. Figure 14 is a photograph of a Type IV A60 sandwich panel which contained a fire. Buckling of the steel structure was prevented and the wall panels could be replaced witout any steel support replacement.

Figure 14: Contained fire on G21 Fire Panel, Type IV A60 sandwich wall (2014)

2. CROSSOVERS

The 1st Type of offshore walls, the “stressed skin” Type, originates from the shipbuilding industry. The 2nd Type, the “corrugated skin” Type, originates from the transport industry. The 3rd Type, the “bolted built-up” Type, originates from the building industry and the 4th Type, the “sandwich panels” Type, originates from prefabricated modules. Figure 15 indicates crossover dates between the various wall Types. In order to start from the beginning of offshore exploration, Type 0, the “wooden walkboard” Type, is also referred to.



Type	Offshore wall type		Origin	Crossover date
0	wood structure	←	walkboard	1900
I	stressed skin	←	shipbuilding	1950
II	corrugated skin	←	containerisation	1965
III	built-up wall	←	building	1975
IV	sandwich panel	←	prefabricated module	2010

Figure 15: Crossovers between offshore wall types

Although wood can still be found offshore on some helidecks, it has not been used on new-build structures for many decades for obvious reasons such as the fire resistance, maintainability, and design life. However, all other wall Types are still in use. Even today, many offshore structures are built as stressed skin and large modules especially tend to be designed as monocoque structures using load-bearing walls, executed either as stressed or corrugated skins. Very large modules are however too heavy to lift, transport and/or install if built as monocoque structures. Floating platforms, however, don’t have such lifting or transport issues. Figures 16 to 19 show the various 4 Types of walls used on modules.

Type IV walls do show a resemblance with internal walls for living quarter areas where B-rated panels can span up to a maximum of about 3200 mm and are usually used to create rooms and hallways within monocoque structures (see Figure 20). Such B-rated walls however do not meet the required criteria to be considered as an alternative for A- and H-rated wall systems, which must be able to span longer than 6000 mm.

Type I, 85 kg/m2

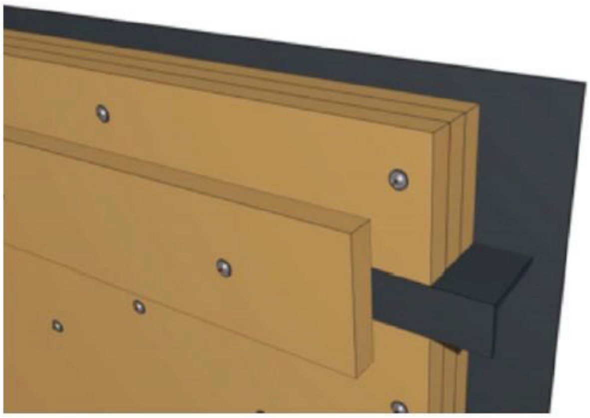


Figure 16: Bulkhead Type (Traditional ship design)

Type II, 55 kg/m2

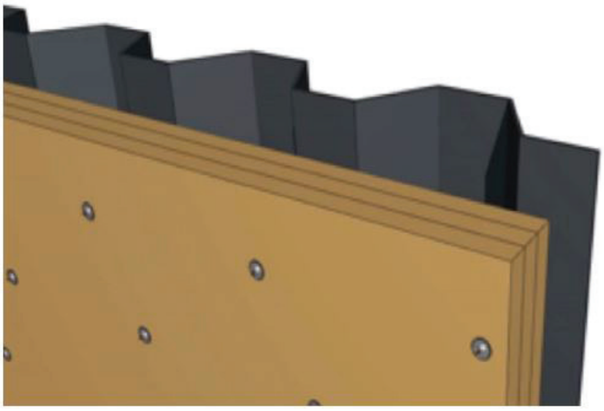


Figure 17: Welded panels (Container design)

Type III, 40 kg/m2

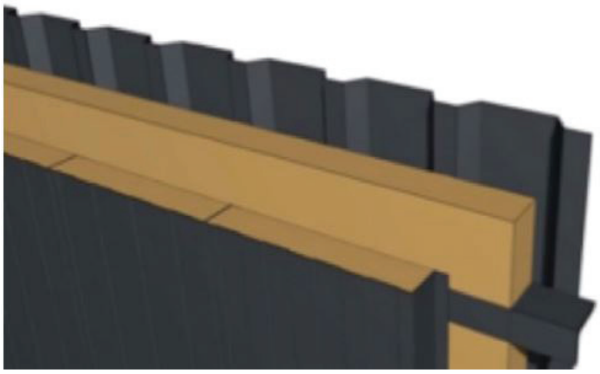


Figure 18: Built-up insulated wall system

Type IV, 26 kg/m2

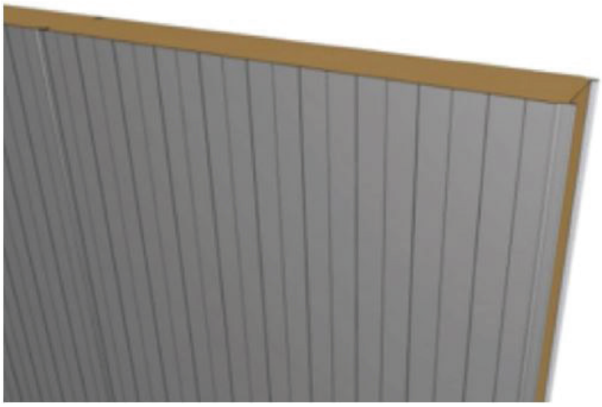


Figure 19: Prefabricated sandwich construction

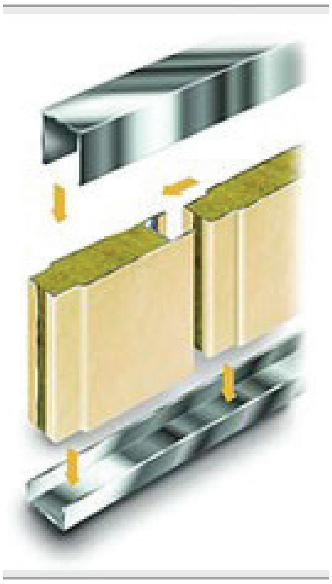


Figure 20: B30 internal wall system

2.1 Design Philosophy for Offshore Structures

There are three different dominant types of offshore structures: fixed structures, subsea structures and floaters. Before the start of the design, a number of criteria should be taken into consideration: the location and function of the platform, field development options and transport and installation of the structure. During the feasibility study phase of any offshore project, design decisions are made regarding the type of offshore structure. In the early FEED phase (Front End Engineering Design), the project group has to decide on the type of structure (i.e. a monocoque shipbuilding structure, or a framed, industrial type structure). A direct consequence of such decision is that it limits options with regard to the type of fire walls to be used, since Types III and IV are non-load bearing walls requiring a framed steel support structure.

Hybrid structures do exist and it is possible for Type III walls to be bolted and act as non-load bearing walls. Type IV walls can also be used on monocoque structures where some of the walls are non load-bearing. In general, the weight of non-load bearing walls can be decreased by using Types III or IV walls. For the purpose of this paper, hybrid structures are however not considered.

3. MONOCOQUE OR FRAMED CONSTRUCTION

A non-scientific research study showed that 85% of the lead design engineers in 2010 originally graduated as naval architects. These engineers learnt to read and write ship designs. There is however a growing number of young lead design engineers who originally graduated as mechanical or structural engineers. This is the same situation for shipyards and module fabricators, where lead designers in shipyards are traditionally naval architects and structural engineers in module fabricators. This is illustrated in Figure 21.

Dominant design philosophy:

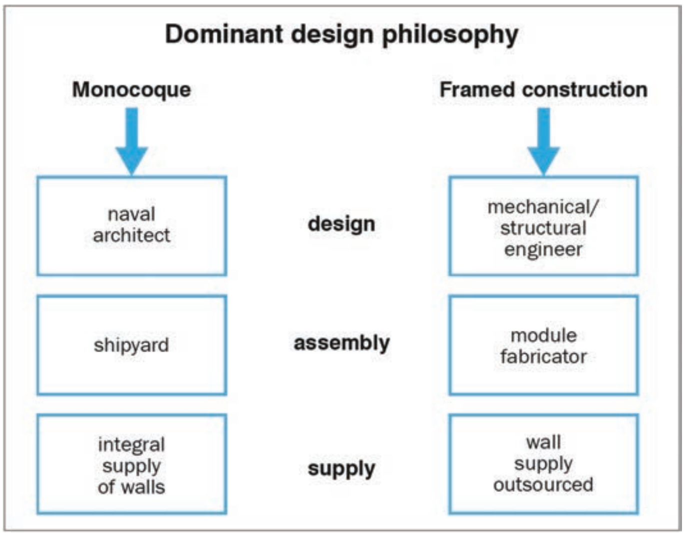


Figure 21: Monocoque vs. framed construction

The 4 Types of walls can be allocated to the two “philosophies” of structural engineering: the use of stressed skin or corrugated skin (Types I and II) provide the walls with load-bearing capacity, thus resulting in a fully welded monocoque structure whereas Types III and IV are non-load bearing walls and thus require a load-bearing support structure. Table 2 lists some key differences between monocoque and framed construction with respect to offshore blast and fire walls.

MONOCOQUE VS FRAMED CONSTRUCTION
FOR OFFSHORE FIRE AND BLAST WALLS

CRITERIA	MONOCOQUE	FRAMED CONSTRUCTION
Weight saving	No	Yes
Installation technique	Welding	Bolting
Installation phase	Early	Late
Installation time	High	Low
Coating	Post-coat	Pre-coat
Fire certificates	Good	Good

Table 2: Monocoque vs framed construction for offshore blast and fire walls

Changing a design from a monocoque to a framed construction is a radical change which will only be carried out when there is a fundamental need. Another question to be asked might be: why do new offshore platforms tend to have a framed construction? Over the past decades, the optimisation of field yield has led to an increasing demand for additional, heavier equipment. When adding equipment to an existing platform, weight is always a key parameter. This is the case for high yield platforms and even more so for the recently introduced offshore wind HVDC transformer platforms. These transformers require ample space and early feed studies of a 100 x 40 x 26 m HVDC platform demonstrated that the originally adopted monocoque design was too heavy to be installed in the shallow waters of the German Bight. The quickest solution to reduce weight was to change the design from monocoque to framed construction and use Type IV sandwich panels as fire rated external envelope and also for internal partitioning. Sandwich panels are typically produced on a continuous production line, and are tested and certified according to strict norms [5].

4. SELECTION CRITERIA

This section provides an overview of the relevant criteria for the design of modules in order to assist design engineers in addressing all functional requirements during preliminary design studies. Trade-offs are addressed and these can be optimised. The decision model underpinned by such criteria can be a useful tool for design engineers. Hard criteria are mandatory whereas soft criteria provide scalable value to the project. Some of the criteria are quantified in offshore standards and well known calculation models. Is the new Type of H120 rated bolted fire & blast walls as good as it claims to be? This section provides the pros and cons of the 4 different Types of blast and fire walls.

The following hard criteria are addressed:

Resistance (blast, fire, fire post-blast, wind, impact), structural integrity/free span, load-bearing capacity, acoustic insulation, tightness (weather, air).

The following soft criteria are addressed:

Weight saving, production and installation cost saving, applicability to arctic environments, thermal insulation, design life, corrosion resistance, free span, loadbearing capacity during fire, transport and installation absorption capabilities, allowance for penetrations, maintenance/repairability and sustainability.

4.1 Hard selection criteria

4.1.1 Fire resistance

The fire resistance of external walls for modules is expressed as either an A-, H- or J-rating.

Fire resistance
The function of walls and decks in the event of a fire is to provide enough time to:

- evacuate people;
- reduce damage to the installation whilst the fire is being extinguished.

The regulations relevant to these criteria provide detailed requirements for the shipbuilding industry (SOLAS 1974 [6]) and modules [7, 8, 9, 10, 11].

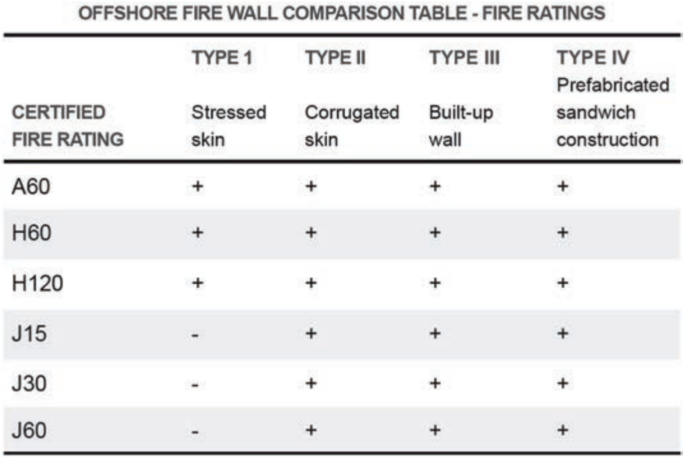
Such requirements assume cellulosic fires, which are simulated in a test furnace in accordance with a temperature rise following a defined curve, reaching 940˚C within 1 hour. A specific test has also been developed to simulate hydrocarbon fires (see Figure 22) and uses the so-called hydrocarbon curve. For this test, the furnace temperature has to rise from 0 to about 900˚C within 3 minutes, and subsequently climb to a steady state temperature of 1150˚C. The behaviour of metallic structures at such temperatures is fundamentally different from that observed during the cellulosic or A-class test, as the material has hardly any strength left at these temperatures.

When a module is certified, it is assumed that a series of successful fire tests of its various components will also provide a fire safe overall construction. Tests carried out by several laboratories have however shown that tests on a combination of two certified components can result in a failure. For example, this may happen in cases where a window is tested in a fire bulkhead. As such, it is advised to test as many components as possible in combination.

Light gauge metal constructions for walls and decks will perform better in the event of a fire than bulkier/heavier forms of construction because distortions will occur (through buckling) rather than large forces being transferred to the supporting structure, which can cause cracks or even collapse.

Figure 22: Jet fire test of Type III fire wall

Table 3 indicates the certified fire ratings for the 4 different Types of fire walls.



OFFSHORE FIRE WALL COMPARISON TABLE - FIRE RATINGS

CERTIFIED FIRE RATING	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
A60	+	+	+	+
H60	+	+	+	+
H120	+	+	+	+
J15	-	+	+	+
J30	-	+	+	+
J60	-	+	+	+

Table 3: Offshore fire wall comparison - Fire ratings

4.1.2 Explosion resistance / weight

The blast resistance of walls is expressed as the combination of overpressure (Bar) and duration (ms). For detonations from an explosive device, the duration is usually short e.g. 20 milliseconds. Hydrocarbon explosions generate lower overpressures but have a longer duration e.g. 200 milliseconds. In addition, the negative phase of the explosion (negative pressure) also has to be taken into consideration [12, 13].

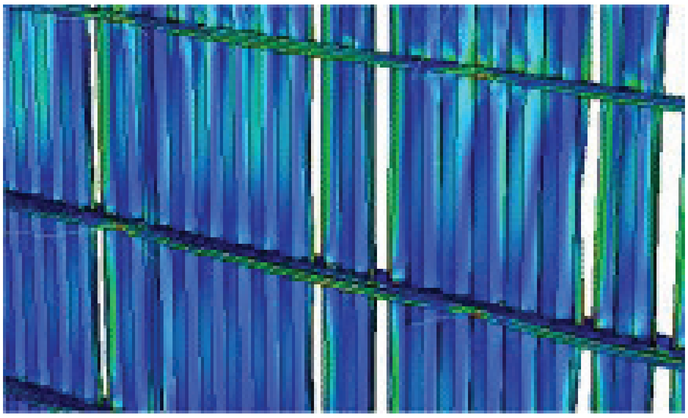
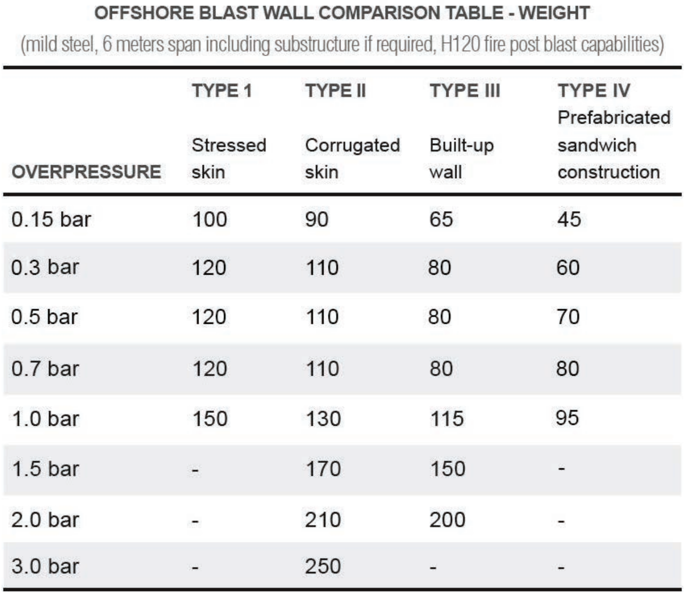


Figure 23: Feasability study for Type II blast resistant wall

Extensive literature exists regarding the modelling of various Types of blast walls [14]. In addition, a number of blast tests have been carried out in certified laboratories to validate such models. Based on such literature, it can be concluded that the dominant Type of blast wall currently in use on modules is Type II. The corrugated shape of the Type II walls can be optimised through analysis by varying blast load and free span. Table 4 indicates opportunities for Type IV walls for overpressures up to 1.0 bar.



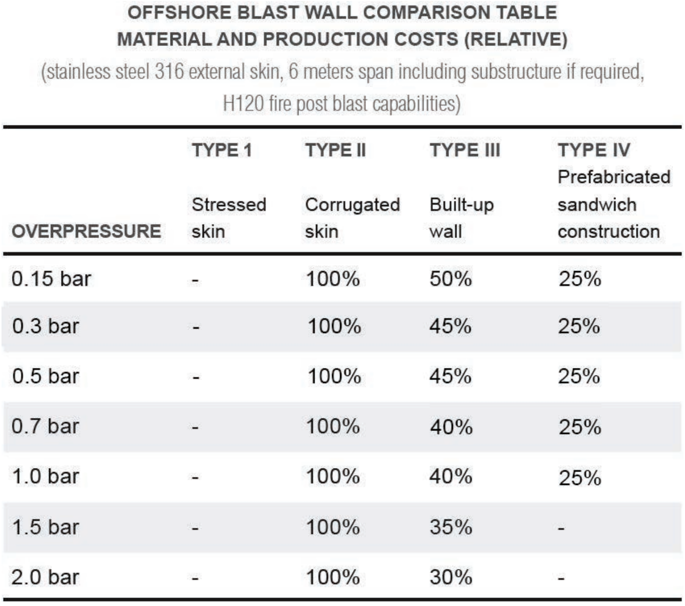
OFFSHORE BLAST WALL COMPARISON TABLE - WEIGHT

(mild steel, 6 meters span including substructure if required, H120 fire post blast capabilities)

OVERPRESSURE	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
0.15 bar	100	90	65	45
0.3 bar	120	110	80	60
0.5 bar	120	110	80	70
0.7 bar	120	110	80	80
1.0 bar	150	130	115	95
1.5 bar	-	170	150	-
2.0 bar	-	210	200	-
3.0 bar	-	250	-	-

Table 4: module blast wall comparison table – Weight

Table 5 indicates relative material and production costs for various Types of blast and fire rated walls. It should be noted that no data was available for Type I stainless steel 316 blast resistant walls, the data for Types II is based on a simply supported assumption, and the data for Type III to IV accounts for membrane effects.



OFFSHORE BLAST WALL COMPARISON TABLE
MATERIAL AND PRODUCTION COSTS (RELATIVE)

(stainless steel 316 external skin, 6 meters span including substructure if required, H120 fire post blast capabilities)

OVERPRESSURE	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
0.15 bar	-	100%	50%	25%
0.3 bar	-	100%	45%	25%
0.5 bar	-	100%	45%	25%
0.7 bar	-	100%	40%	25%
1.0 bar	-	100%	40%	25%
1.5 bar	-	100%	35%	-
2.0 bar	-	100%	30%	-

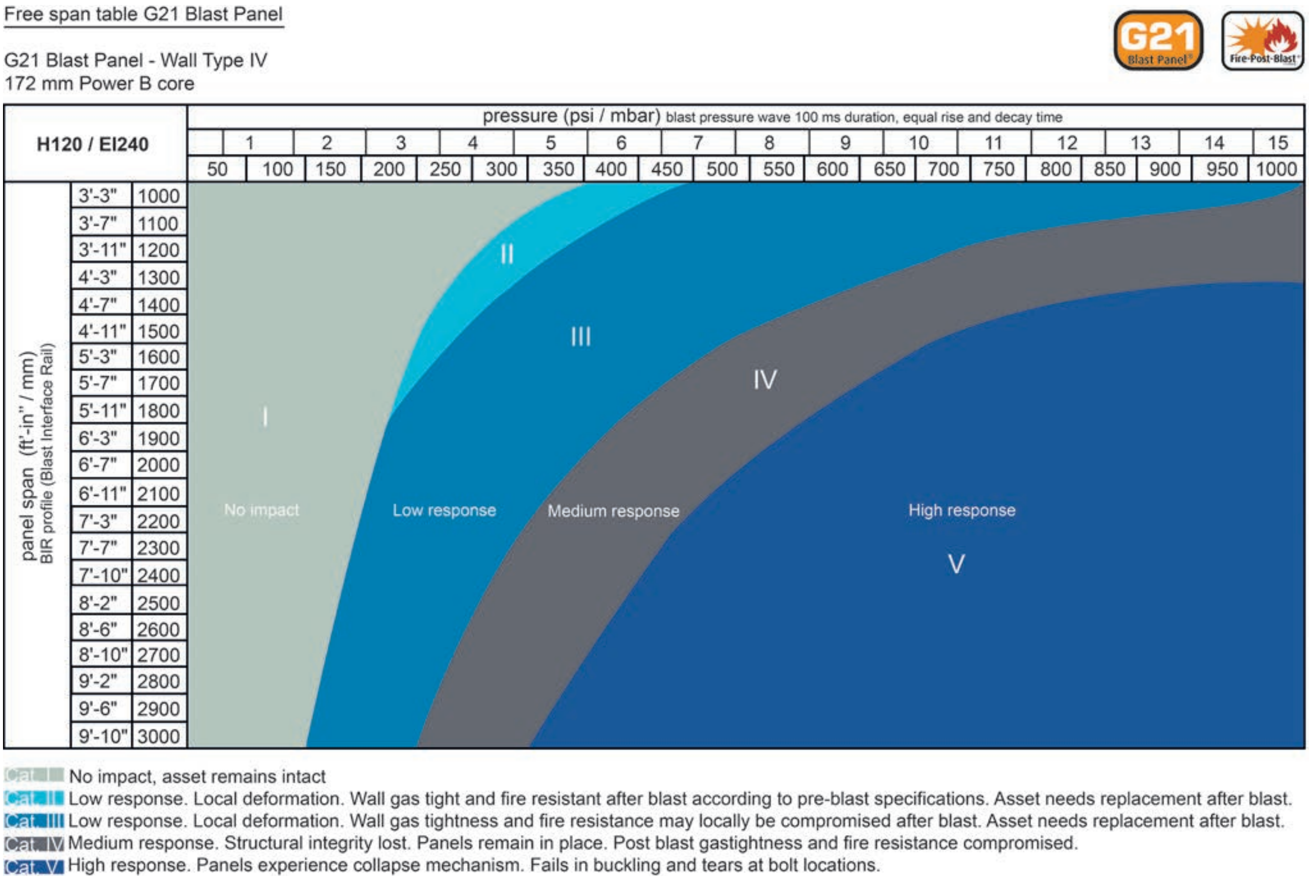
Table 5: Module blast wall comparison table – Material and production costs

4.1.3 Fire post-blast resistance

In most accidental events involving explosions, the blast is followed by a fire. In order to replicate real life scenarios in laboratory tests, some clients prescribe fire post-blast tests on walls. Strangely enough, only one of the 4 Types of walls is tested on fire post-blast in an accredited way as shown in Table 6 as well as Figures 24 and 25.

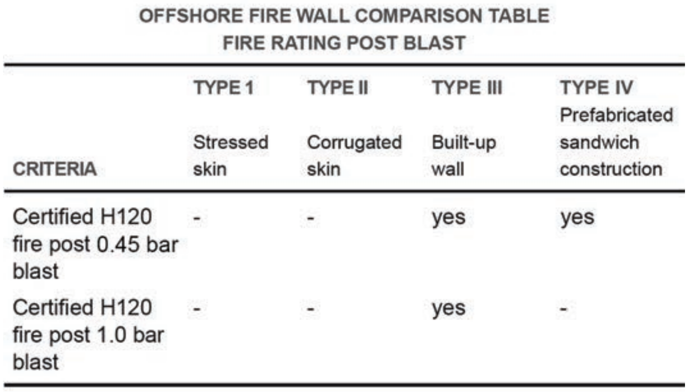
Figure 24: Type III wall exposed side after 1.0 bar blast prior to H120 fire

Figure 25: Type III wall exposed side after 1.0 bar blast and and prior to H120 fire H180 fire



Cat. I No impact, asset remains intact
Cat. II Low response. Local deformation. Wall gas tight and fire resistant after blast according to pre-blast specifications. Asset needs replacement after blast.
Cat. III Low response. Local deformation. Wall gas tightness and fire resistance may locally be compromised after blast. Asset needs replacement after blast.
Cat. IV Medium response. Structural integrity lost. Panels remain in place. Post blast gastightness and fire resistance compromised.
Cat. V High response. Panels experience collapse mechanism. Fails in buckling and tears at bolt locations.

Figure 26: Free span table G21 Blast Panel



OFFSHORE FIRE WALL COMPARISON TABLE
FIRE RATING POST BLAST

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Certified H120 fire post 0.45 bar blast	-	-	yes	yes
Certified H120 fire post 1.0 bar blast	-	-	yes	-

Table 6: Post blast fire resistance certification

Figure 27: 0.25 bar blast test G21 Blast Panel

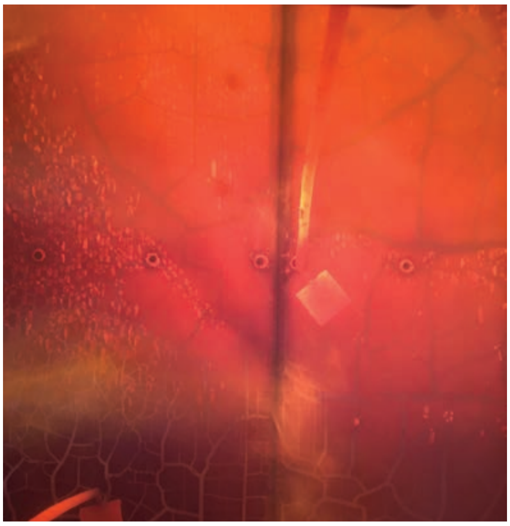


Figure 28: H120 fire post blast test of G21 Blast Panel – hot side

4.1.4 Other hard criteria

A number of other hard criteria should be taken into consideration to provide a fit-for-purpose wall design. The following paragraphs introduce such criteria and the performance of the 4 wall Types against these criteria is summarised in Table 7.

Wind load resistance
For external walls, wind loading is a critical design factor. This is especially the case for high-rise modules where wind load pressures can be as high as 250 kg/m2. Depending on the height of a free span, wind loads can lead to the requirement for additional support structures.

Impact resistance
Steel walls are sensitive to high energy impacts on small areas, and this is more the case for light weight steel constructions than for heavy weight constructions. This criterion should be taken into consideration when the project comprises specific potential high energy impact scenarios.

Air tightness
In order to avoid gas ingress, occupied rooms on modules are continuously over-pressurised (generally at 50 Pa). As walls are part of the envelope, these should be sufficiently air-tight to allow the HVAC system to maintain the required overpressure, regardless of the external environment. Walls are therefore required to satisfy a minimum level of air-tighness and all wall Types are tested and approved with regard to air-tightness according to the limits of the HVAC system.

In-situ blower door tests generally indicate that most of the air leakage originates from the penetrations in the walls and not the walls themselves. Such leakages can usually be easily remedied once identified and those designing walls should use good practice penetration details regardless of wall Type.

Weather tightness
Weather tightness is also important for all types of offshore structures. Weather tightness should not be mistaken for water tightness. When considering water tightness, a number of metres of water column has to be withstood, and a Type I walls is the obvious choice for this purpose as ship hulls have been built as Type I for many decades.

If rain water tightness (weather tightness) is the only requirement, then walls need to be able to withstand rain, even in heavy storm conditions. All wall Types are capable of maintaining weather tightness under such conditions.

Green water loads (loads from splashing sea water) may also apply during transport and/or installation and if so, project specific requirements should be taken into consideration.

The Type IV sandwich panel is capable of withstanding significant green water loads as well as pressures of up to 1200 Pa in terms of weather tightness. Not all Type IV wall systems share equal weather tightness properties.

Acoustic insulation
The standard requirement in terms of acoustic insulation for all wall Types on modules is about 32 dB (A). Specific areas such as generator rooms can require additional acoustic insulation, and this can be achieved relatively easily by adding an additional layer to create a mass-spring-mass construction where the (acoustic, thermal and fire) insulation layer acts as a spring. With such additional layer, an acoustic insulation of over 50 dB (A) can be achieved on all wall Types.

OFFSHORE FIRE WALL COMPARISON TABLE
OTHER HARD CRITERIA

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Wind load resistance (150/250 kg/m²)	++	++	+	+
Impact resistance (10 kJ @ 10" diameter)	++	++	+	+
Air tightness (<1.0 m³/m²/h)	++	++	++	++
Weather tightness (no leackage @ 1200 Pa overpressure)	++	++	++	++
Acoustic insulation (Ra > 32 dB(A))	++	++	++	++

Table 7: fire wall comparison table – Other hard criteria

4.2 Soft selection criteria

4.2.1 Weight saving

Weight saving is becoming increasingly important for modularized installations. Table 8 provides a comparison for A60 fire walls across the 4 Types, and the advantage of using the more recent wall Types when weight considerations are important can be seen. This is due to the fact that no support structure is required for Type IV prefabricated sandwich panel walls.

OFFSHORE FIRE WALL COMPARISON TABLE - WEIGHT
(Internal A60 wall, 5000 mm free span)

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefab sandwich construction
Weight (kg/m²)	85	55	40	26

Table 8: Weight comparison for internal A60 fire walls

For welded wall Type II, welded supports can be added when extra spans are required. For bolted Types (Type III and IV), bolted support structures can also be added. These can be optimised cold formed steel elements spanning between already existing columns, thus only leading to limited additional weight as shown in Figure 29.

Figure 29: G21 Fire Panel, Type IV wall with C profile adding 5 kg/m2 to the total wall system

Table 9 provides a weight comparison for external A60 fire walls across the 4 wall types.

OFFSHORE FIRE WALL COMPARISON TABLE - WEIGHT
(External A60 wall, 7000 mm deck to deck span, including weight of support structure)

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Weight (kg/m²)	105	70	50	33

Table 9: Weight comparison for external A60 fire walls

4.2.2 Production cost saving

The production costs of the 4 Types of walls significantly differ. Some aspects can have a significant impact on the total cost and should be taken into consideration. For example, post-welding passivation is required for welded stainless steel walls (Types I and II are welded constructions), which is time consuming and costly. Types III and IV walls do not require welding and thus do not require passivation, which gives them a cost advantage. Type IV walls are also considerably lighter than Type I walls and require less material to produce. Types III and IV can also be pre-painted and manufactured on automated production lines. This ensures both consistent quality and cost-effective production. Table 10 provides a comparison of the overall production costs for the 4 wall Types.

OFFSHORE FIRE WALL COMPARISON TABLE - OVERALL COST

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Overall Cost	100%	80%	60%	40%

Table 10: Overall cost comparison table

Installation cost saving

The dominant drivers with regard to installation time are whether a wall is bolted or welded and whether coating is applied before or after installation. Other factors include the efficiency of yard personnel and use of efficient tools for installation. Table 11 provides a comparison of installation time for the 4 wall Types and Figures 27 and 28 show the installation of Types II and IV walls.

OFFSHORE FIRE WALL COMPARISON TABLE - INSTALLATION TIME

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Installation time	100%	70%	60%	15%

Table 11: Installation time comparison table

Figure 30: Type II welded wall

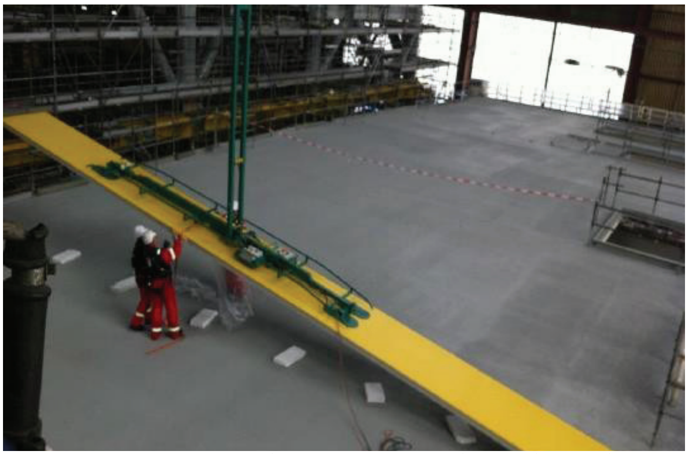


Figure 31: G21 Fire Panel, Type IV sandwich panel, 14m long, during installation

4.2.4 Applicability to Arctic environment / thermal insulation

With trillions of cubic meters of gas and billions of barrels of oil reserves estimated in the Arctic, located in relatively shallow waters offshore and more easily available due to de-icing, the exploitation of fossil fuels in this region is becoming more and more feasible.

A key contributing factor to safety at work in the Arctic is the provision of workspaces at ambient temperatures for the personnel. In such a harsh environment, the requirement for adequate wall thermal insulation is evident and the avoidance of cold bridging between the outside and inside is paramount. Types I and II walls introduce serious cold bridges at the wall-floor and wall-roof connections since all the construction details are welded, as can be seen in Figure 32. Type III walls still comprise numerous thermal bridges as shown in Figure 33. Type IV walls, however, have virtually no cold bridges and can therefore easily create a workable environment, as shown in Figure 34.

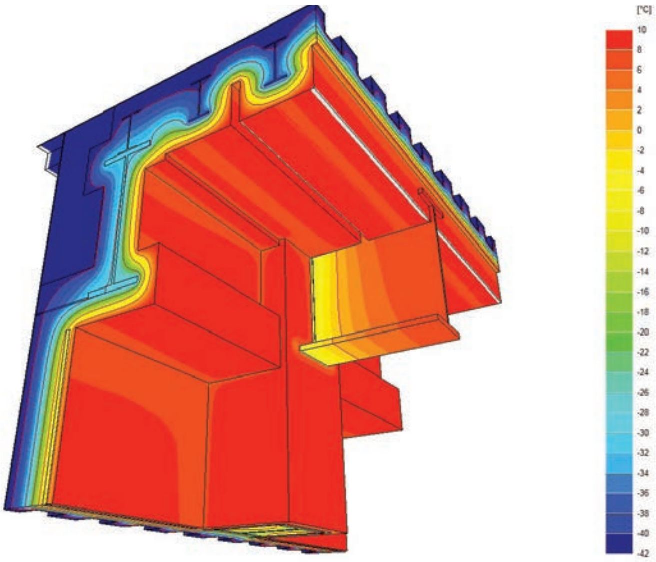


Figure 32: Cold bridges on Type II monocoque wall

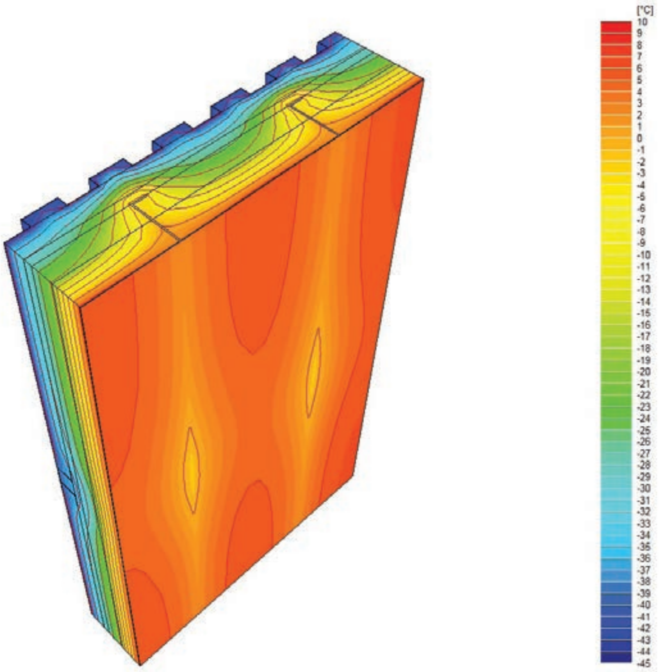


Figure 33: Cold bridges on Type III wall

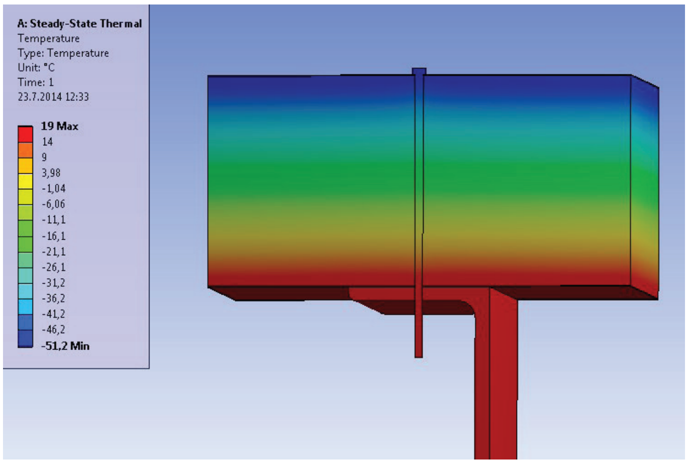
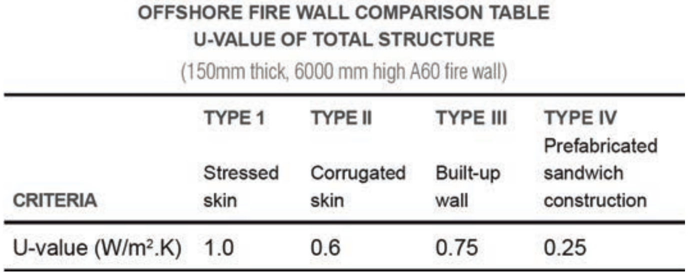


Figure 34: G21 Fire Panel, Type IV wall uniform temperature profile

The calculation of the main thermal insulation property, the U-value, in Watts per square metre Kelvin (W/m2.K), should always account for cold bridges within the wall construction as shown in Figures 32 to 34. A good U-value can always be obtained when ignoring cold bridges in the calculation, but these can really reduce thermal performance depending on the design and Type of wall system. Significant cold bridges within a wall construction can result in unwanted condensation, draught and even the unability of the HVAC system to provide an acceptable indoor environment for very low outdoor temperatures. Table 12 provides calculated U-values for the 4 wall Types.



OFFSHORE FIRE WALL COMPARISON TABLE
U-VALUE OF TOTAL STRUCTURE
(150mm thick, 6000 mm high A60 fire wall)

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
U-value (W/m².K)	1.0	0.6	0.75	0.25

Table 12: U-value comparison for total wall structure

4.2.5 Brittleness of steel in Arctic environment

For blast walls in the Arctic, the EN 1993-1-10: 2005 standard should specifically be taken into consideration. Engineers should take into account the defined factors reducing the maximum allowed thickness on the use of S235JR steel for instance. Alternatively, higher steel grades can be used or welding should be avoided.

4.2.6 Longevity/corrosion resistance

Most modules are used in salt water and have an original design life of 30+ years. Advances in technology have led to increased field yield, and recent installations are generally designed for a 50 year design life, preferably without any downtime for the renovation of fire walls.

For many platforms that are now more than 30 years old, the maintenance of their external envelopes has been far from adequate over the years. This was confirmed by recently carried out surveys and is illustrated in Figure 35.

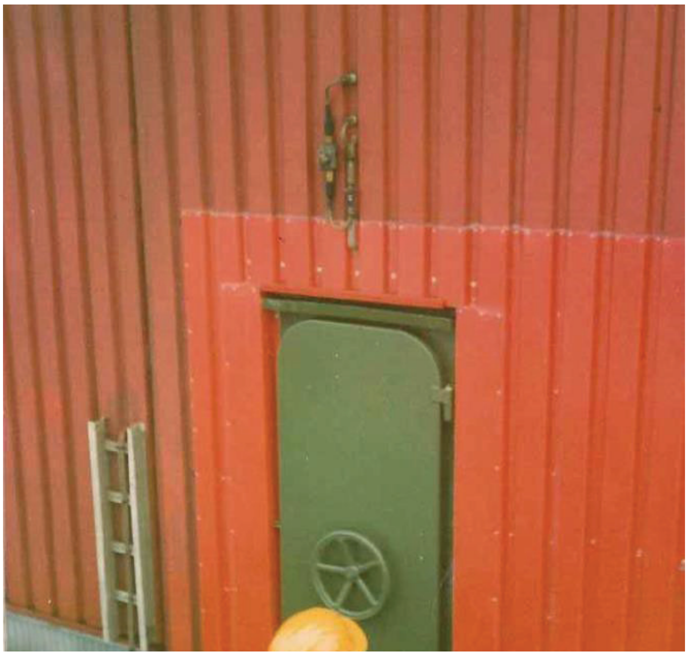


Figure 35: 30 years exposed Plastisol Type III fire wall with a recent modification using the same material

Global paint suppliers have recently made considerable progress in applying paint on mild steel as a corrosion protection layer. The number of years of warranty for the coating is however still limited as compared to the design life, and taking this criterion into account for assessing the cost over the design life of a solution is important (see Table 13).

When using the Types III and IV light gauge wall constructions, the use of stainless steel walls will be a lot less expensive than in conventional heavier forms of constructions. This can be explained by the following reasons:

- Light gauge walls only require stainless steel on the external face (0.7 mm thick) to provide a 40 year maintenance free design life (see Figure 33). However, for Types I and II walls, the monolithic structure requires the entire steel (3-10 mm thick) to be in stainless steel;

- 0.7 mm thick stainless steel 316 L can be supplied with automated factory pre-painting, with no painting being required after installation;

- As Types III and IV are bolted walls and there is no need for passivation of stainless steel. Passivation is only required for welded, non-post-painted constructions such as Types I and II walls.

Figure 36: Stainless steel Type III built-up wall exposed for 33 years. Note the difference with the mild steel lighting and walkway supports.

OFFSHORE FIRE WALL COMPARISON TABLE
DESIGN LIFE AND COATING WARRANTY (FREE SPAN)

CRITERIA	TYPE 1	TYPE II	TYPE III	TYPE IV
	Stressed skin	Corrugated skin	Built-up wall	Prefabricated sandwich construction
Design life mild steel	20 years	20 years	20 years	30 years
Design life stainless steel 316	-	50 years	40 years	50 years
Warranty mild steel	5 years	5 years	10 years	30 years (G21 Fire Panel)
Warranty stainless steel 316	-	-	20 years	20 years

Table 13: Offshore fire wall comparison table – Design life and coating warranty

4.2.7 Allowance for penetrations

Firewalls do require penetrations for HVAC (Heating, Ventilaction and Air Conditioning), MCT (Multi-Cable Transit) and Pipes, and these can can be accommodated by all wall Types. Welded constructions Types I and II require welding to accommodate penetrations. Such welding should take place before passivation/painting of the wall panels and requires detailed engineering and pre-installation of all penetrations months prior to installation of walls (see Figure 37). Bolted constructions such as Types III and IV walls can accommodate penetrations post-installation (see Figure 38). Table 14 provides a comparison of the 4 wall Types with regard to penetrations. Since more Type IV suppliers will enter the market, buyers should be alert to make sure relevant type approvals including penetrations free span capabilities are in place.

Figure 37: Type II welded wall, pre installation of penetrations required

Figure 38: G21 Fire Panel, Type IV bolted wall, installation of penetrations on the spot

OFFSHORE FIRE WALL COMPARISON TABLE - PENETRATIONS

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Penetration prior/post installation of wall	Prior	Prior	Post	Post
Installation time for wall penetrations	100%	100%	40%	30%
Lead time for changed penetrations	On the spot	8 weeks	On the spot	On the spot
Hot work requirement for changes at site	Yes	Yes	No	No

Table 14: Offshore wal comparison table - Penetrations

4.2.8 Free span

For all 4 wall Types, the maximum free (unsupported) span depends on a number of factors and can be optimised. Table 15 compares the free span of all 4 Types based on standard construction variables and considering both the A60 insulation and steel thicknesses.

OFFSHORE A60 FIRE WALL COMPARISON TABLE - FREE SPAN (MILD STEEL)

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
150 mm total thickness, external loading 2.5 kPa wind pressure and suction, load factor 1.5	5.0 m	5.0 m	4.5 m	4.4 m
120 mm total thickness, external loading 2.5 kPa wind pressure and suction, load factor 1.5	4.0 m	4.0 m	3.5 m	3.6 m
<150 mm total thickness, internal loading 0.6 kPa wind pressure and suction, load factor 1.5	5.0 m	6.0 m	5.0 m	5.7 m

Table 15: Offshore fire wall comparison table - Free span

4.2.9 Loadbearing capacity during fire

As mentioned in the section covering safety, the loadbearing capacity during a fire event should be taken into consideration. In the case of load bearing walls i.e. Types I or II, these may collapse prematurely if their steel side is subjected to a fire and may cause the entire structure to collapse.

In the case of non-loadbearing walls i.e. Types III or IV, local loads may cause premature buckling of the walls. This can be prevented by either making sure that local loads are released during fire (by using brackets designed to fail at 150˚C for instance) or using a local support structure instead.

4.2.10 Transport & installation deflections absorption capacity

All modular buildings which are not built onsite need to be transported and installed. During these stages, deflections of the main steel structure will occur, with the extent of such deflections depending on a number of factors, such as the type of transport, lifting and the strength of the whole structure.

As discussed in previous sections, fire walls can be load bearing (Types I and II) or non load-bearing (Types III and IV). In both cases, the wall should be able to absorb the deflections of the main structure due to transport and lifting.

Type II walls are only optimised for weight saving and are known to be sensitive to buckling. In general, welded connections can only absorb limited deflections whereas bolted connections can absorb larger deflections and cope more easily with the deflections of the main structure. The structural response to transport and lifting loads (including deflections) can be assessed via finite element analysis.

Generally, the welded wall Types (I and II) are typically part of a rigid, heavier monocoque construction whereas the bolted Types (III and IV) are typically part of lighter and more flexible framed construction.

4.2.11 Maintenance/repairability

Maintenance and repairability are important factors with respect to both the long-term, uninterrupted use of the offshore installation and the total cost of ownership (see also the section covering longevity). Recent (and tested) innovations on both

pre-coatings and post-coatings allow for long service lives with decreasing maintenance costs.
Types I and II require hot work to repair unplanned penetrations, which can occur due to accidental impacts or misplacement of penetrations during construction. Type III and IV penetrations can however be restored via certified solutions which do not require hot-work. Table 16 provides a comparison of the 4 wall Types regarding the maintenance and repairability criteria.

OFFSHORE FIRE WALL COMPARISON TABLE - MAINTENANCE/ REPAIRABILITY (MILD STEEL)

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Base layer prior to coating	Black steel	Black steel	AluZinc	AluZinc
Post-coat or pre-coat	Post-coat	Post-coat	Pre-coat	Pre-coat
Onsite paint repair possible	Yes	Yes	Yes	Yes
Hot work required to repair unplanned penetrations	Yes	Yes	No	No

Table 16: Comparison table - Maintenance / repairability

4.2.12 Cradle-to-cradle

Steel as a material fits perfectly within the cradle-to-cradle principle. The steel used within steel-intensive blast and fire wall solutions is likely to have been produced from recycled steel, and the same applies to the stone-wool insulation used for the A- and H-rated Type IV panels. The coating differs from one wall Type to another since the total dry coating layer thickness for the welded Types (I and II) is considerably higher than for the pre-coated bolted Types (III and IV).

In addition, regular over-painting is required for welded structures to maintain their integrity in the harsh offshore environment, unless stainless steel is used. It appears that the lighter the solution is and the less expensive it is throughout its lifecycle, the better it is in terms of environmental impact. Type IV walls are the lightest and require less material to produce. This bolted system is also easy to remove and separate after use as shown in Figures 39 and 40.

Based on the above discussion, the comparison table 17 can be derived, although the conclusions are open for discussion.

Figure 39: Shredder for obsolete stone wool filled panel

Figure 40: Automated separator in shredder

OFFSHORE FIRE WALL COMPARISON TABLE - CRADLE-TO-CRADLE (MILD STEEL)

CRITERIA	TYPE 1 Stressed skin	TYPE II Corrugated skin	TYPE III Built-up wall	TYPE IV Prefabricated sandwich construction
Energy required for production	100%	80%	60%	40%
Paint required over 40 year design life	100%	100%	40%	40%
Energy required for removal and separation after use	100%	90%	40%	50%
Possibility to re-use materials	90%	90%	95%	95%
Overall cradle-to-cradle rank	4	3	2	1

Table 17: Cradle-to-cradle comparison

4.2.13 Further cost saving

By having a good understanding of the whole set of design criteria, one is able to make strategic decisions for the design of offshore fire walls. It is indeed essential to understand that the choice of type of structure (framed construction versus monocoque) and the possibility to optimise each fire wall can lead to cost, weight and installation time savings.

This paper aims to challenge readers with a view to facilitate the selection of the best blast and fire wall design according to all project specific hard and soft requirements. In an era where oil prices are expected to remain well under $ 100 per barrel, keeping the budget under control is a continuous exercise for all those involved in the design and construction of modular installations.

Different perspectives regarding cost savings can be adopted, and risk management factors play an important role. Shipbuilding-dominated yards will appreciate Type IV prefabricated walls differently than module fabricators, simply due to their lack of experience with this Type of wall system.

In order to make a quick assessment of the wall Type to use based on the criteria discussed in this paper, the following rules of thumb can be observed:

- Type IV walls can be used with a free span up to 5.7 metres without requiring any support structure depending on supplier;

- For Arctic projects, framed construction should be used in order to use Type IV walls whose thermal insulation properties can provide an optimal working environment with a thermal insulation value for total envelope U=0.30 W/m^{2}K;

- As Type IV walls are lighter, these are more cost effective and easier to install than other Types and this Type can be used by default for all non-load bearing fire walls;

- If additional fire or blast walls are required on existing installations, Type IV walls have the advantage of being light-weight, having short delivery times and being easy to adjust and install onsite;

- Type IV walls are the preferred solution for blast and fire rated walls up to 1,0 bar overpressure.

4.2.14 Suggestion for future research

Currently, structural engineers are not allowed to impose heavy lateral loads on Types III and IV bolted walls, the main reason being that in the event of a fire, such loads can cause unpredictable behaviour for these walls. However, lateral loads can be absorbed by these wall Types during transport and installation, and especially by the Type IV prefabricated sandwich panels. Future research could inform structural engineers on the ability of these panels to resist in-plane shear, particularly due to platform movements, thus allowing for further steel and weight savings.

5. SUMMARY OF DECISION MODEL

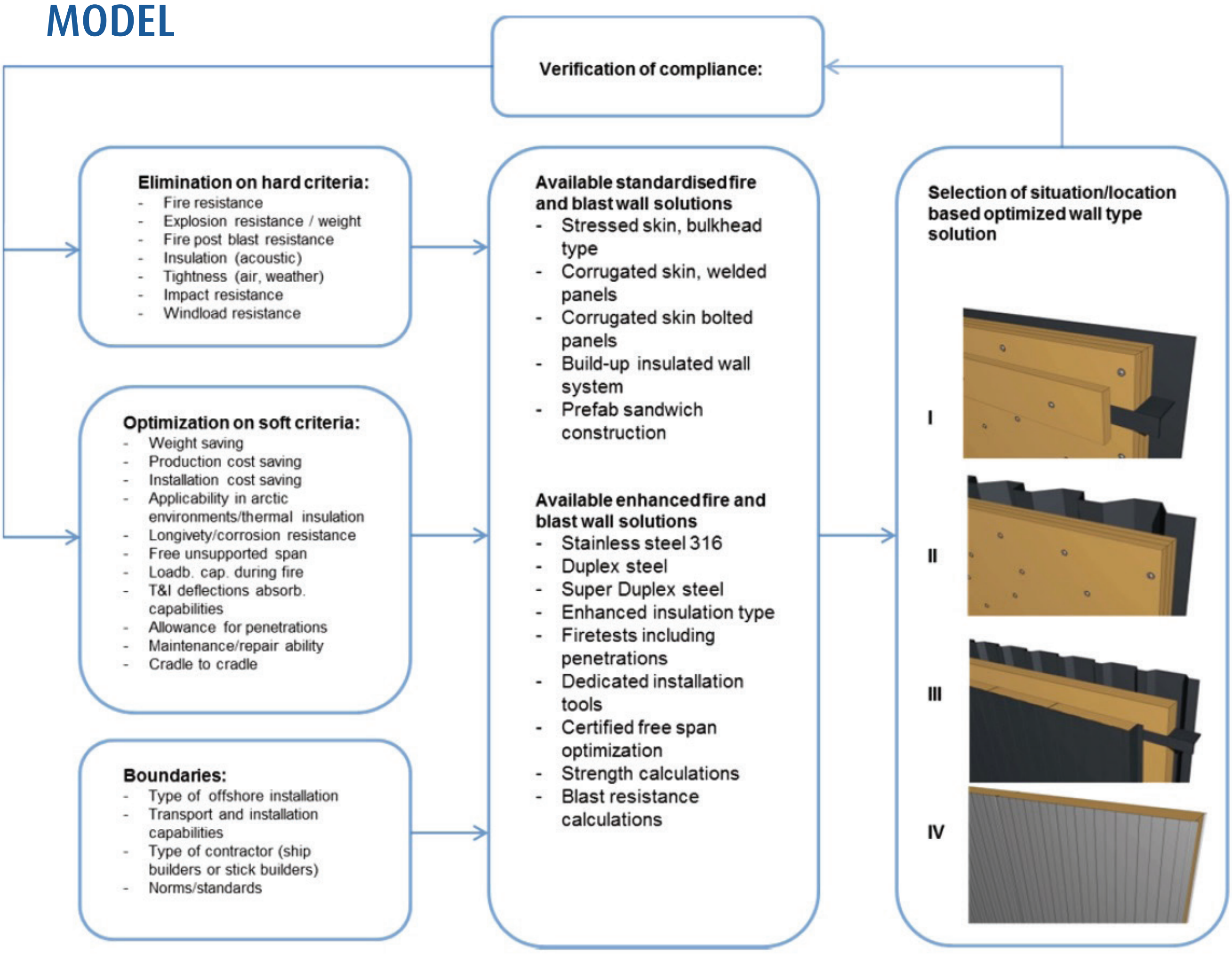


Figure 41: Fire wall optimisation decision model

6. PRACTICAL SOLUTIONS AND DETAILS

In conclusion on wall Type IV, the following examples of practical solutions and design recommendations can be given.

With the use of vacuum-lifting systems, 17m^2 external walls can be installed “in one go” as shown in Figure 42, allowing for the installation of 200m^2 of wall per crew per shift. No intermediate supports are required for the internal panels shown in Figure 43, with a maximum free span of 6 up to 10 metres.

As can be seen in Figure 44, in the case of a penetration through a wall, steel plates can be welded to the main steel to provide a fully certified and air-tight penetration. The self-drilling and self-tapping screws used for fixing the panels to the steel supports can be either capped (as shown) or cut to prevent safety hazards.
As shown in Figure 45, lightweight items such as signs, cables and switches can be fixed directly onto Type IV walls. Heavy equipment can be installed on panels via the use of unistrut supports as well as the secondary steel supporting the panels themselves.

Figure 46 shows an A60 sandwich panel as well as a A60 bolted removable panel including bolted, lightweight galvanized cold formed secondary support structure, which can also be used as support to E&I equipment. Penetrations such as the one shown in Figure 47 (for a door) do not require any “top to bottom” support structure, and the combination of doors and panels is fire rated.

The stainless steel nose shown in Figure 48 above the MCT’s is required to avoid water ingress.
The T-junction in Figure 49 shows a cold formed C-section penetrating the internal wall (for wind loads). Such penetrations are gastight and fire proof.

Figure 42: Installation of a G21 Type IV A60 Firewall by crane

Figure 43: A60 and H60 rated G21 Type IV walls in battery room

Figure 44: Penetration through H120 rated G21 Fire Panels

Figure 45: H120 G21 Firewall including supports for eletrical equipment

Figure 46: A60 rated G21 panel and bolted removable panel

Figure 47: A60 rated G21 FirePanel and A60 single leaf hinged door

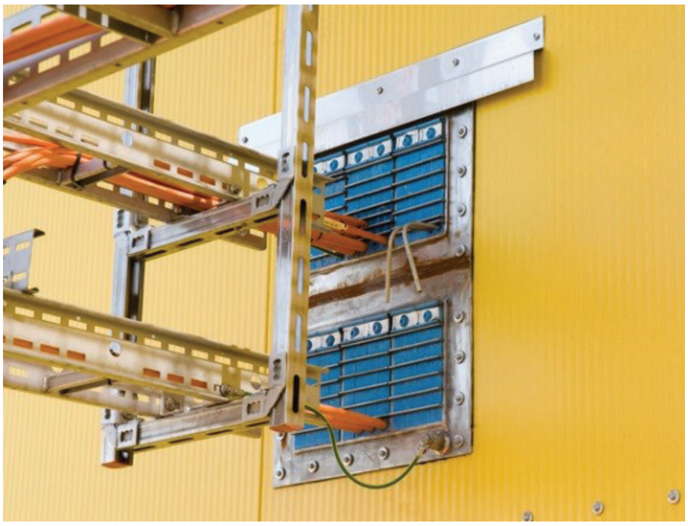


Figure 48: External A60 rated G21 FirePanel including A60 MCT's by Roxtec

Figure 49: T-junction between external and internal A60 rated G21 FirePanel

Figure 50: H120 G21 FirePanel / deck connection detail

Figure 50 shows the flashings used to cover the panel screw ends at the connection with the deck.

Figure 51: H120 G21 FirePanel / deck connection detail

Figure 51 shows the cover caps used tt cover the panel screw ends. A 100 x 50 x 6 mm secondary steel angle bar is welded to the deck at the yard and is coated prior to the installation of the panels.

Figure 52: H60 rated G21 Blast panel 0,3 bar blast overpressure including G21 doors and windows. Fire post blast capabilities.

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