THE EFFECT OF RELIEF PANELS ON GAS EXPLOSION OVERPRESSURE

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AUTHOR BIOGRAPHICAL NOTES

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ABSTRACT

Explosion relief panels are commonly used on offshore installations to improve working environment and at the same time allow venting of gas explosions to control explosion risk. This is very important particularly in arctic regions where requirements for acceptable working environment may easily conflict with requirements for low explosion risk.

Explosion relief panels have been tested in low congestion, medium scale explosion tests, and based on such tests it has been concluded that replacing solid walls with relief panels reduces explosion loads significantly.

It is not clear whether this conclusion can be extended to real offshore modules, which are significantly larger and more congested. In the present paper the gas explosion simulator FLACS is therefore used to investigate the effect of different wall configurations (e.g. open, solid or relief panels) on explosion overpressure in a large, highly congested offshore module.

The objective is to assess whether in reality similar benefits from using relief panels as seen in the experiments can be expected.

INTRODUCTION

Background

Explosion relief panels are commonly used in colder climates to ensure acceptable working conditions as well as sufficient explosion venting. These panels shall give a rapid ventilation of the pressures generated by an explosion. The principles for this are based on experiments in both medium and large scale. Tests done at GexCon's test site [1,2,3,4] indicate that the panels open rapidly and in many cases provide sufficient ventilation for the burning gases to expand and hence limit overpressures. However the equipment and pipe congestion in these experiments are lower than what is found on typical offshore modules. Hence it was thought that on actual installations flame acceleration may be high enough to produce high overpressures even with the additional vent areas provided by the panels. This was the basis for the work reported in this paper.

Objectives

The objectives of the presented work are to find out if the explosion relief panels function as expected in high congestion areas in offshore modules, and to compare results from explosion simulations with open walls, with pressure relief panels and with solid walls.

Explosion basics

Important factors that influence a gas explosion are

- gas cloud size and composition,
- degree of congestion of equipment, piping and structure
- ventilation areas and ventilation arrangement

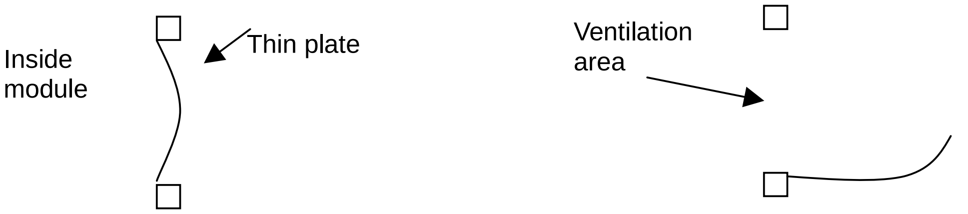
The larger and closer to stoichiometric concentration a gas cloud is, the faster a flame can propagate through the cloud. Also, the more congested the volume inside the cloud is, the faster the flame can propagate. And the higher the burning velocity, the higher is the overpressure. When gas burns it tries to expand, and if expansion is hindered by barriers like walls and decks, pressure will increase.

Explosion venting is achieved by providing sufficiently large and sensibly located open areas in walls or decks, to enable the gas to expand out from the area where the explosion occurs. For high flame speeds larger vent areas are required to keep pressure down, than for lower flame speeds. When the flame is fast enough, it may not be possible to provide large enough vent areas to control the overpressures – the inertia of surrounding air may provide enough confinement for high overpressures to be generated.

Offshore modules are often large enough to be able to sustain the build-up of large clouds, and they are often very congested, hence the possibility to generate high overpressures exist. Even if substantial parts of walls and decks are constructed as explosion relief panels, the ventilation area provided may not be effective enough in controlling the pressure rise.

Explosion ventilation

A pressure relief wall is an alternative wall construction thought to combine the requirements for acceptable working conditions and gas explosion safety. A relief wall is mainly a frame with a thin plate covering the frame. If an explosion should occur, the plate will break loose on the rim and collapse. When the paper refers to relief walls, these will be denoted panels. Figure 1 shows a hinged pressure relief panel.



Before an explosion

During and after an explosion

Figure 1. Explosion relief panel, hinged type.

Pressure relief panels are commonly used in the process and offshore industry as mitigating devices to reduce consequences of explosions. When the pressure forces on a panel exceed a certain limit, the panel yields and the pressure is relieved to the atmosphere. There are different opening mechanics for pressure relief panels. One of the opening mechanisms is that each sub panel (the panel consists of sub panels mounted on a frame) turns on a hinge when it opens. This avoids the issue of projectiles being generated by the panels.

If gas is released into a module, the pressure relief panels will contribute to keep the gas cloud inside the module. This may increase the probability for the gas cloud to ignite. If the walls are open the gas will be ventilated out of the module. The faster a gas cloud can be ventilated out of the module, the less is the probability that the gas cloud will ignite. Note however that the present paper does not address the effect of relief panels on gas cloud buildup.

FLACS

FLACS is a 3-dimensional CFD code for simulating gas explosions, ventilation and gas dispersion in complex geometries like offshore modules. In the code one can define a large amount of parameters describing the scenarios to be investigated. Mitigating devices like water deluge and pressure reducing equipment like pressure relief panels can be implemented in the geometry. Interactions between the flame, ventilation areas and obstacles are handled in the code. The geometry is divided into a set of control volumes, and the FLACS code will solve the full gas dynamic partial differential equations for these control volumes. Turbulence and chemical reactions are included in the differential equations. The code includes the effect of the turbulence by solving equations for turbulent kinetic energy and its rate of decay. For more information see www.gexcon.com.

GEOMETRY DESCRIPTION

Introduction

The geometry used in this work is based on an existing offshore module, and the module is highly congested. A FLACS representation of the geometry has been produced to enable the simulations described in the paper to be performed. This chapter presents a description of the geometry of the module, location and the packing density of the equipment. The term equipment is here taken to describe all types of equipment, boxes, pipes, cables and smaller obstacles.

Geometry with solid walls in the north and south side

The module is initially open at both ends and closed along the sides, see Figure 2. The east end of the module has openings in the corners of the floor and the roof, and some of the decks in this end are porous. This means that gas or fluid can flow through the decks. The module is rectangular in shape.

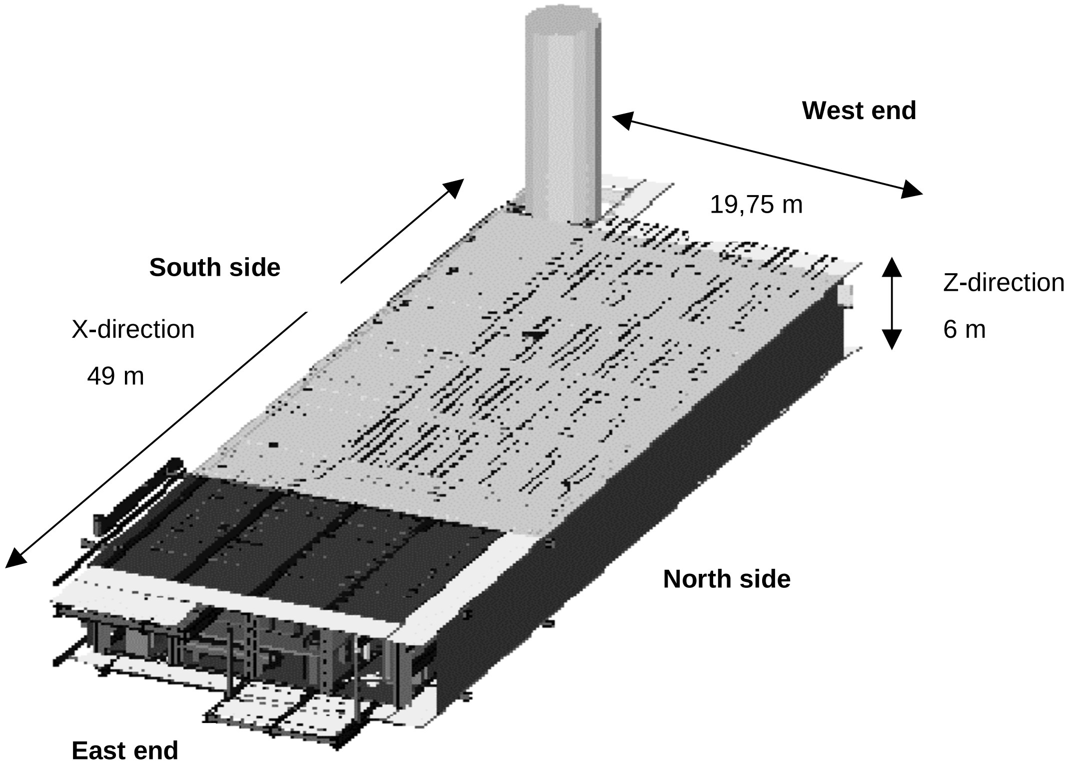


Figure 2. The geometry of the module used in the simulations.

Figure 3 shows a cross-section of the geometry and gives an indication of the obstacle density in the module. As can be seen, the east end is less congested than the west end.

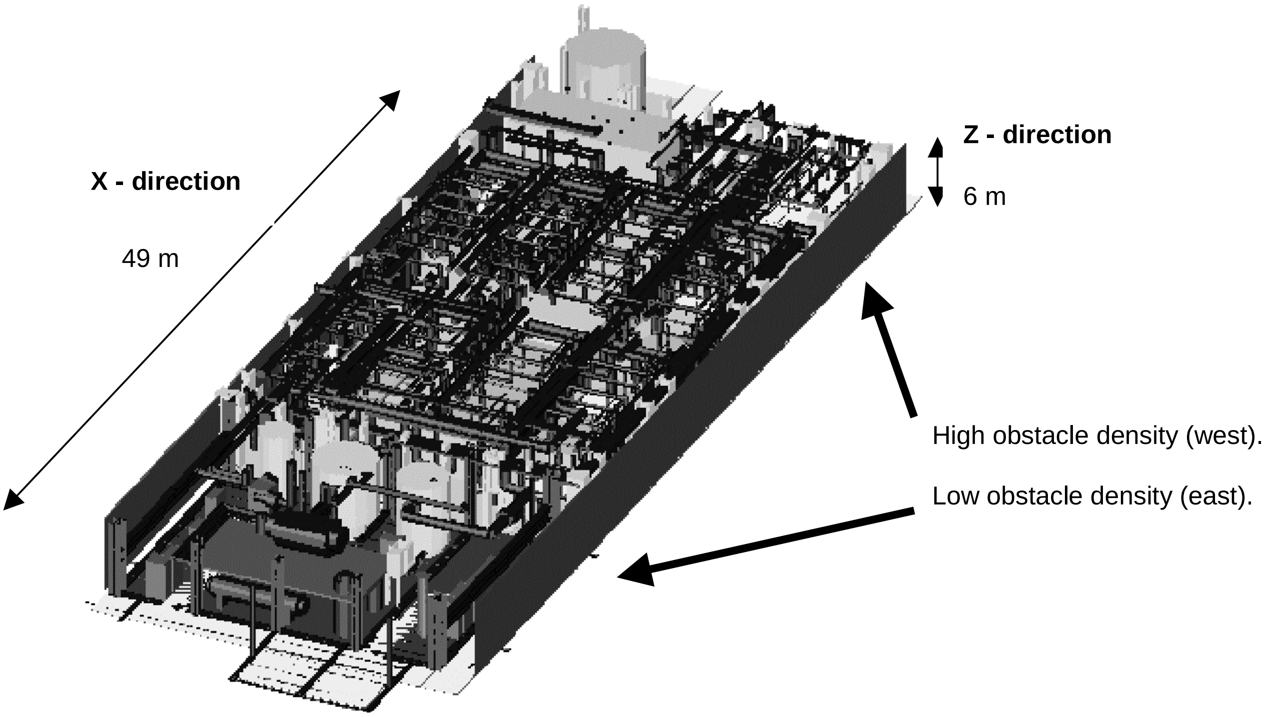


Figure 3. A cross section of the geometry

SCENARIOS

Scope

To meet the objectives of the work a series of simulations have been performed. The parameters varied are wall configuration, gas cloud size and ignition location. The gas clouds are stoichiometric natural gas-air mixtures.

FLACS 99 has been used for the simulations. A number of monitor points and panels have been placed inside the module to measure local drag and panel average pressure.

The following parameters are varied in the simulations:

- Gas cloud (100%, 50% and 25%)
- Location of gas cloud (east and west for the 50% cloud, in addition middle for the 25% cloud)
- Ignition location (Relative to each cloud: east, middle and west)

In addition the wall configurations are as follows:

- The south (long) wall is always solid
- The north, east and west walls may be solid, covered by relief panels or open

Monitor points and monitor panels

There are 82 monitor points (for drag) located within the module. These are placed along the floor, walls, roof, near pipes and equipment.

There are 19 monitor panels along the walls and decks. The panels are square in shape where the length of the sides is 4 meters. These monitor panels are used to measure panel average pressure.

Pressure relief panels

The pressure relief panels used in the simulations are square in shape. They are 4 metres wide and the thickness of the panel is 2 mm, this gives a mass of 16.2 kg per panel.

The panels are split up into sub sizes of 1 metre in length and 1 metre in height. The panels will be placed from 1 metre above the floor to 1 metre under the roof in the module, under and over the pressure relief panels there will be louver panels which will stay in place during the explosion simulations.

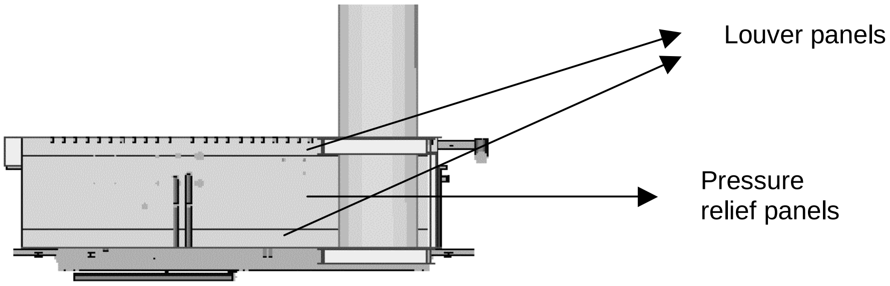


Figure 4. **Illustration of the distribution of louver and pressure relief panels**

RESULTS AND DISCUSSION

The discussion is based on the results from the simulations. Mainly the results for the 50% and 25% gas clouds are discussed in this chapter. The reason for this is that the overpressures with the 100% gas cloud are very high and in many cases differ little regardless of the wall configuration.

Results

Tables 1 and 2 contain maximum panel overpressures measured at the south (solid) wall. The overpressures in the tables are given in barg.

Table 1. **The maximum panel average pressure from the monitor panels in the south wall. Solid north and south walls.**

Gas cloud size		100%			50%			25%				
Gas cloud location					W	W	E	W	M	E	M	M
Ignition position		W	M	E	W	E	E	W	M	E	E	W
Wall configuration	Open	10,18	11,09	13,05	7,25	8,87	7,06	1,65	2,84	0,12	2,93	2,61
	Panel west	10,03	11,70	13,20	8,47	8,54	7,09	3,93	2,87	0,10	2,90	2,62
	Panel east	10,26	11,04	12,89	7,18	8,88	7,00	1,64	2,84	0,23	2,89	2,61
	Panel west and east	10,04	11,68	13,10	8,50	8,51	7,04	3,94	2,86	0,23	2,89	2,63
	Solid west	10,19	14,06	15,19	7,27	14,59	8,11	4,38	3,02	0,06	2,75	2,68
	Solid east	10,23	10,99	12,32	7,21	8,94	8,15	1,63	2,80	1,16	2,87	2,61

Table 2. **The maximum panel average pressure from the monitor panels in the south wall. Solid south wall.**

Gas cloud size		100%			50%			25%				
Gas cloud location					W	W	E	W	M	E	M	M
Ignition location		W	M	E	W	E	E	W	M	E	E	W
Wall configuration	Open	10,23	11,22	12,02	7,83	9,23	7,86	1,98	2,79	0,13	2,46	2,60
	Panel north	10,24	10,44	12,17	7,97	8,63	7,55	1,95	2,50	0,17	2,58	2,42
	Panel north and west	9,83	11,01	12,29	7,85	8,83	7,57	3,92	2,52	0,17	2,59	2,44
	Panel north and east	10,24	10,42	12,01	7,96	8,66	7,02	1,95	2,51	0,20	2,52	2,44
	Panel north, west and east	9,83	11,03	12,11	7,87	8,85	7,00	3,92	2,52	0,20	2,53	2,44
	Panel north, solid west	9,86	13,82	12,43	7,98	13,98	7,64	5,62	2,56	0,16	2,55	2,46
	Panel north, solid east	10,27	10,47	11,62	7,97	8,64	7,79	1,95	2,51	0,86	2,52	2,42
	Panel north and east, solid west	9,86	13,88	12,25	7,98	13,99	7,04	5,62	2,57	0,20	2,51	2,46
	Panel north and west, solid east	9,84	10,98	11,68	7,85	8,82	7,80	3,92	2,52	0,86	2,52	2,44
	Panel north, solid west and east	9,86	13,95	11,74	7,97	14,09	7,80	5,62	2,57	0,86	2,53	2,45

Gas cloud located at the ends

With a 50% gas cloud located and ignited in the western end of the module where there is a high degree of congestion, the pressure-increasing effect of having relief panels instead of an open area near the ignition point is clear. The reduction in pressure against the south wall when changing the end from a solid wall to pressure relief panels is small.

With a 25% gas cloud there is a significant increase in pressure when having pressure relief panels instead of an open wall. The expanding combustion products will be pushed into the module with ignition near the pressure relief panels. This will generate turbulence in the unburnt gas, and eventually generate a higher pressure. The same effect will occur with a solid wall near the ignition point. When the pressure is high enough to open the panels, the expansion will ventilate through the open parts of the wall. This is why the solid wall will generate a bit more turbulence and a higher pressure with a 25% gas cloud.

For a small gas cloud located in the east, the pressures are significantly lower than for the similarly sized cloud located in the middle or the west end of the module. This is due to most of the congestion being located in the west and middle parts of the module. Hence less turbulence generation and lower overpressure is expected for the eastern cloud.

When the 25% gas cloud is located and ignited near the east end wall, there will be a big reduction of the pressure against the walls and decks when changing the east wall from a solid wall to pressure relief panels.

There is clearly no reduction in pressure against the south wall, when having pressure relief panels instead of a solid wall on the north side of the module. This applies to the 25% gas cloud and ignition located in the west and east ends of the module. The reduction will not be affected by the wall configurations in the west end. The pressure relief panels will generate a higher pressure than the solid wall, when the west end is either open or closed. When there are pressure relief panels in the west end the results are similar for the two wall configurations.

With a 50% gas cloud located and ignited in the west end, there will be an insignificant decrease of the pressure against the south wall and decks when changing the north wall from a solid wall to pressure relief panels.

The solid wall will generate a higher pressure than the pressure relief panels in the north side, when having either pressure relief panels or a solid wall in the east, less congested end. This applies to a 25% gas cloud located in the east end.

The solid wall or pressure relief panels will make the expansion of the combustion products push unburnt gas towards the middle of the module. This area is highly obstructed, and hence the solid wall will generate a much higher pressure against the south wall and decks. This will also occur with the pressure relief panels, but to a lesser extent. With pressure relief panels on the north side, some of the unburnt gas will ventilate through these. This will not occur with the solid wall, hence the solid wall will generate the highest pressure against the south wall and decks.

Having a solid wall in the north side instead of pressure relief panels will generate the highest pressure against the decks for all the scenarios with a 25% gas cloud, except when the gas cloud is located in the east, and there is a solid wall in the west end.

Gas cloud located in the centre

When the 25% gas cloud is located in the middle of the module, the solid wall in the north side will generate the highest pressure against the south wall and decks. This is the case if the gas cloud is ignited in either the west, middle or east end. The wall configurations in the east end will not have any significant effect on the pressure build up in the module.

With pressure relief panels on the north side, there will not be any difference in the results when changing either end from a solid wall to pressure relief panels. With the ignition in the middle and west end, there will be higher pressure when having the ends open, than with other wall configurations.

For many of the scenarios where the ignition is in the end of the module, there is insignificant decrease of the pressure against the south wall and decks when changing a solid wall to pressure relief panels.

For the 100% gas cloud trends are similar to the 50% gas clouds. With the ignition in the west end, there are no significant differences between a solid wall or pressure relief panels in the north. When the ignition is in the middle or east and with a solid wall in the west end, there will be a pressure build up against the west wall. This will be less dominant with pressure relief panels on the north side.

CONCLUSIONS

176 simulations have been performed in the FLACS99 simulator, to study the effect of pressure relief panels on explosion overpressure. The offshore module used in the simulations is rectangular in shape and open in both ends. It is highly congested, except in the east end. The wall configurations are varied for the ends (west and east) and for one of the long walls (north) in the module. The results from the simulations are the maximum panel average pressure and the maximum drag on the equipment. In this paper only overpressure results are presented and discussed.

From the results one can draw the following conclusions, which are specific to this geometry:

Wall configuration changes which do not lead to improvement

- The reduction of maximum pressure against the long wall will be insignificant for most of the scenarios, when changing a solid end wall to pressure relief panels. This applies to the 50% cloud and ignition near the end in a high congestion module.
- Changing one of the long walls from a solid wall to pressure relief panels, will for all the 50% cloud scenarios give an insignificant reduction of the maximum pressure against the remaining long wall.
- Changing one of the long walls from a solid wall to pressure relief panels, will give an insignificant reduction of the maximum pressure against the remaining long wall for most of the scenarios, for a 25% gas cloud and ignition near an end in a module with high equipment congestion. In some of the scenarios with ignition near an end with a low degree of congestion, there will be insignificant reduction of the maximum pressure against the decks.

Wall configuration changes which do lead to improvement

- In the scenarios with a 50% cloud near an end, ignited in the middle of the module, there will be significant decrease of the maximum pressure against the walls and decks, when changing a solid end wall to pressure relief panels.
- There will be a significant reduction of the maximum pressure against the walls and decks when changing the end from a solid wall to pressure relief panels. This applies to most scenarios igniting a 50% gas cloud near an end with a low degree of congestion.
- In all the scenarios where the ignition and the gas cloud are far from the explosion relief panels, the panels will have no significant effect on pressure buildup and will act as open walls. This is because the pressure from the moving unburnt gas will be higher than the required opening pressure for the relief panels.
- Changing one of the long walls from a solid wall to one based on relief panels, will for the majority of cases give a significant reduction of maximum pressure against the remaining long wall and the decks. This applies to the 25% gas cloud, located in the middle or at the east end.
- Using pressure relief panels instead of a solid wall will give rise to larger reductions in overpressure when the cloud is located and ignited in the less congested end of the module, than when it is located and ignited in the more congested end.
- Scenarios with the 25% cloud show more spread in the results than scenarios with the 50% cloud.

The results show that replacing open sides with explosion relief panels does not as a rule lead to overpressure increase, and replacing solid walls with explosion relief panels will not necessarily lead to reduced overpressures. Some observations that can be made are that explosions with ignition far away from a solid wall seem to be more sensitive to replacing the wall with relief panels than when ignition is close to the wall. This also seems to be the case for explosions in clouds located in less congested regions compared to more congested areas. Also venting along the flame path (in this case the north wall) seems to be less effective for higher congestion regions than for regions with lower congestion.

To be able to predict effects like the ones described above, it is necessary to apply methods which can account for local variations in congestion as well as confinement, and how these parameters influence both turbulence generation (and hence flame acceleration) and explosion venting. As an example, local increase of vent areas can lead to increased gas flow through a congested region, and the degree of congestion may determine how this balances, whether pressure increases or decreases. Hence introduction of explosion relief panels needs to be based on scenario-specific, CFD-type explosion analyses. Only in this way can rational assessments of the possible benefits of explosion relief panels be made. Simpler methods would typically be global in nature and cannot be expected to predict the local effects described above.

Note that the present work does not include dispersion analyses. Varying wall configurations will influence the dispersion process and hence resulting cloud size. This gives further support to the conclusion above with regard to the use of CFD as a basis for assessing any benefits of relief panels.

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