OTC 16058

An Integrated Approach for Gas Dispersion, Gas Explosion and Structural Impact Analysis for an Offshore Production Platform on the Dutch Continental Shelf

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Abstract

The design of an offshore gas production platform has been subjected to an extensive quantitative risk analysis in particular with regard to its resistance to gas explosions loads. It was demonstrated that integration of the physical and structural effects of a gas explosion in an early stage of the design results in a safe and economical design.

Introduction

In October 2003 gas was produced for the first time from the Wintershall Q4-C gas production platform located in the North Sea, 30 kilometres offshore the Dutch coast in a water depth of 24 metres (see Figures 1 and 2). The recoverable reserves of the gas reservoir at a depth of 2 kilometres are estimated to be 6 BCM. The reservoir is depleted by two wells and presently producing 3.5 MNm³ gas per day which is evacuated by a submarine pipeline via Unocal's Hoorn platform. The potential production capacity is 7.5 MNm³/day. The platform production facilities are based on the gas dewatering process. The platform is normally not manned. The design of the platform has been carried out by Korndörffer Contracting International (KCI BV), constructed by the construction yard HBG and installed by Seaway Heavy Lifting. The design and construction of the platform have been certified by Bureau Veritas. The Dutch State Supervision of Mines is the supervisory authority. As part of the safety case, an integrated gas dispersion, gas explosion and structural impact analysis has been carried out to assess the impact and risks of a gas explosion.

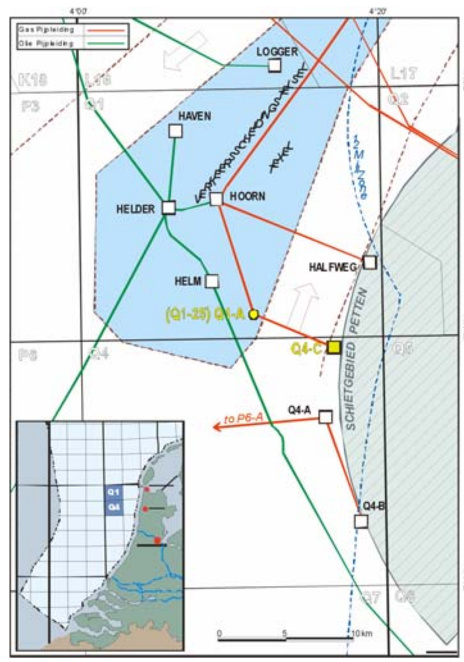


Figure 1: Field location map

Figure 2: Q4-C Gas production platform

Platform Description

The Q4-C platform is a fixed structure consisting of a topside deck structure mounted on a jacket type substructure founded with skirt piles to the sea bottom. The composing components are depicted and described below.

Platform Modules.

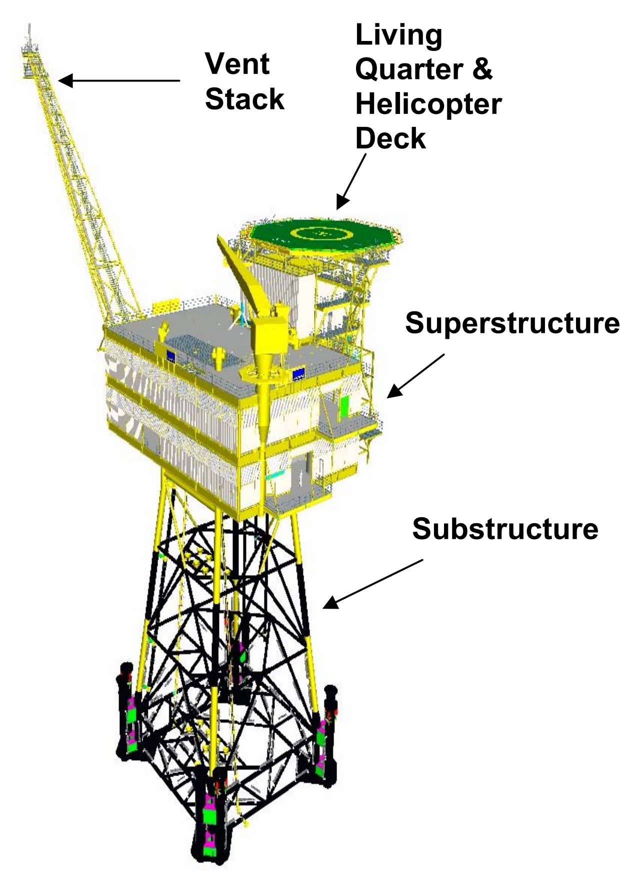


Figure 3: Q4-C Platform

Vent Stack. The vent stack is 45 metres long.

Living Quarter and Helicopter Deck. This module consists of an 11 men living quarter and a helicopter deck. The living quarter also contains, apart from the kitchen and living rooms, the control room for the platform. The second floor houses the sleeping quarters. This entire module weighs 400 tons.

Superstructure. The topsides consist of three decks, which house all process equipment required to dewater the gas for transport to shore by pipeline. The topsides weight is 1800 tons.

Substructure. The jacket is fixed to the seabed by means of eight skirt piles driven 35 meters into the seabed and supporting the topside structures. The jacket weight is 1200 tons.

Superstructure. The superstructure is composed of three decks, being the main deck, production deck and cellar deck.

Main Deck. The main deck supports the deck crane, helicopter deck and living quarters. This deck will be further used as well work over and maintenance operations and equipment. The remaining open area is reserved for future expansions like compression facilities.

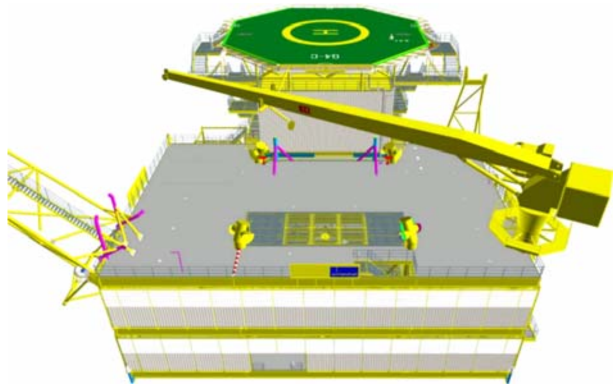


Figure 4: Main deck

Production Deck. The production deck houses the following production facilities and utilities as described and depicted below (see Figure 5).

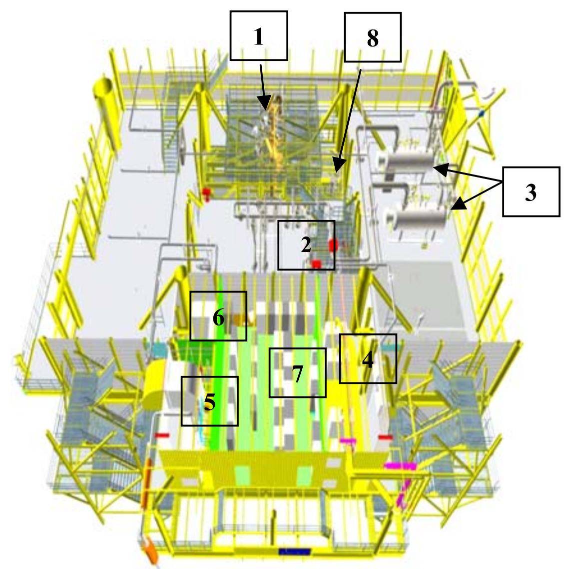


Figure 5: Production deck

1. X-mas tree; the well pressure is 250 bar. The X-mas tree contains a (choke) valve, which reduces the pressure to about 105 bar.
2. The manifold and HIPPS.
3. Two Gas/Liquid Separators. The maximum capacity of each separator is 3.3 MNm^3 gas per day.
4. Four microturbines that generate the required power. They each have a capacity of 60 kW. The produced gas from the platform will be used as fuel.
5. Diesel generator. In case no gas is available for the micro turbines, a diesel generator is present to provide the required electricity for a so called “black-start”.

6. Battery room. Batteries are present to supply electricity to the main equipment during power failure of the micro turbines.

7. Electrical Equipment room. Almost all electrical equipment will be connected to the cabinets in this room. This room is connected to the control room in the living quarter (at the main deck).

8. Sphere Launcher.

Cellar Deck. The produced gas is evacuated from this deck. This deck also contains a "tank farm" for storage of chemicals, diesel and drinking water. The cellar deck houses the following production facilities and utilities as described and depicted below (see Figure 6).

9. Two Liquid / Liquid separators.

10. Two Venturi tubes. A venturi tube is installed to ensure the condensate is being spiked into the gas stream.

11. Export manifold. The produced gas will be collected in this 16-inch pipe, which is connected to the riser in the jacket.

12. Sphere launcher.

13. Vent Knockout vessel.

14. Skimmer.

15. Methanol tank (10 m^3).

16. Glycol tank (20 m^3).

17. Kinetics tank (20 m^3).

18. Water tank (20 m^3).

19. Diesel tank (20 m^3).

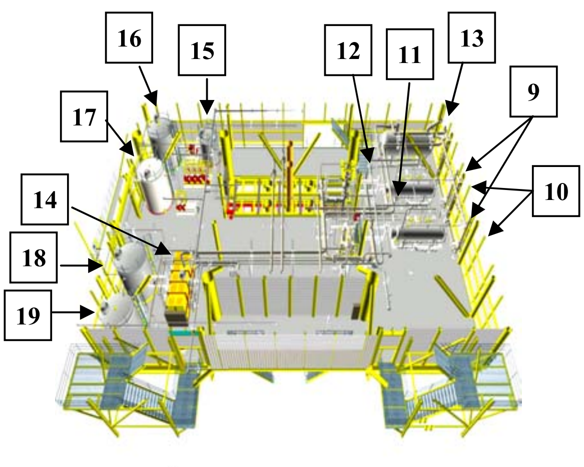


Figure 6: Cellar deck

Explosion Preventive and Mitigating Measures

In order to reduce the risks of a gas explosion on the platform, various preventive and mitigating measures have been taken into account in the design and operational condition. Prevention of gas explosions and effects on offshore platforms is a major issue to be considered in the quantitative risk assessment as part of the safety case, but also compulsory within the framework of the European ATEX directive, 94/9/EC [1]. Risk reduction of a gas explosion on the Q4-C platform is effectuated by the following preventive and mitigating provisions:

Preventive Measures. Following preventive measures were considered:

- Optimization of process equipment lay out and sectioning to reduce hazardous area zones and sizes;
- Limitation of number of flanges to reduce the probability and leakage rates;
- Selection of ATEX classified equipment to reduce the probability of ignition in case of gas leakage;
- Fire and gas detection systems;
- Venting system to release gas in safe area in case of hazardous conditions;
- Process cause and effect control systems.

Mitigating Measures. Following mitigating measures were considered:

- Remote operations (normally not manned platform);
- Location of helicopter deck and living quarters on main deck;
- Shielding location of survival boat;
- Reduction of the wind shielding and creation of maximized natural ventilation to reduce the gas volume in case of gas leakage;
- Application of blast type wind shielding to prevent pressure built up due to explosion (maximum overpressure of 50 mbar);
- Reduction of dead ends to prevent gas explosion pressure built up by orientation and lay out of equipment;
- Application of blast walls between living quarters and control room and process area;
- Blast proof fire/wind screen between stairs and process area;
- Reinforced equipment and piping supports to prevent escalation of gas explosion;
- Clamping of hatches to prevent blow out;
- Structural integrity explosion impact design.

Gas Dispersion, Gas Explosion and Structural Impact Analyses

Objective. The objective is to achieve a condition where explosion risks at the installation are reduced to as low as reasonably practicable (ALARP). Reference is made to the UKOOA/HSE report "Updated Guidance for Fire and Explosion Hazards" [2]. Apart from the preventing and mitigating measures as discussed in section 3, the following goals define what in practise is necessary to achieve an "ALARP" design with respect to explosion hazard:

- To provide the best practicable protection to personnel in the event of a blast;
- To ensure that in the event of a major blast incident, structural integrity will be maintained such as to allow safe evacuation of the platform;
- To ensure that the platform structure will, after a major blast, survive a one-year wave loading;
- To ensure, by using state of the art modelling, an economically attractive design.

The explosion analysis consists of the following steps:

- Determination of the most likely gas cloud volume on the various decks;
- Determination of the release frequency;
- Determination of the ignition points;
- Simulation of the gas cloud explosions;

- Structural impact analysis.

Gas Release and Frequencies. The gas release frequencies, $P_{gas\ leak}$, have been determined for small (7 mm), medium (22 mm) and large (70 mm) holes. This calculation is based on generic failure rates for pipe work, valves, flanges, instrument connections/small bore connections and pressure vessels. Reference is made to E&P forum report "Hydrocarbon Leak And Ignition Database" [3]. The cumulative frequencies of gas releases are based on the total number of pipe work, valves, flanges, instrument connections/small bore connections and pressure vessels. The gas release rates for various hole diameters have been calculated using the program "Rocalc". Using statistical data for the wind directions and velocities, the relative cumulative probability of the number of air changes, $P_{air\ changes}$, has been calculated for various decks. Combining the results, the most likely gas cloud volumes and probability of occurrence have been calculated for the decks.

The joint probability of explosion is:

$$P_{explosion} = P_{air\ changes} \times P_{gas\ leak} \times P_{ignition} \qquad (1)$$

Table 1: Gas Release Frequencies

Event	Release Frequency per Year		
	Small [7 mm]	Medium [22 mm]	Large [70 mm]
Release from isolatable section	$8.31 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$	$1.09 \cdot 10^{-2}$
Sum	$1.24 \cdot 10^{-1}$		

Table 2: Gas Release Probabilities

Event	Release Probability		
	Small [7 mm]	Medium [22 mm]	Large [70 mm]
Release from isolatable section	67 %	24 %	9 %
Sum	100 %		

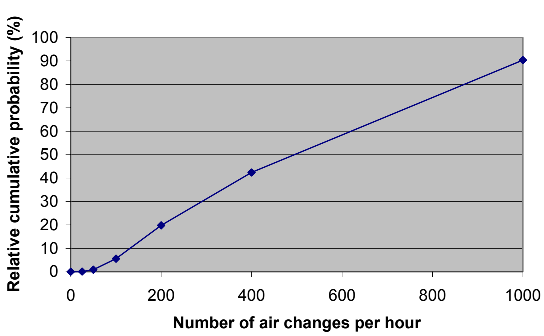


Figure 7: Relative cumulative probability distribution of number of air changes due to natural ventilation on the production deck

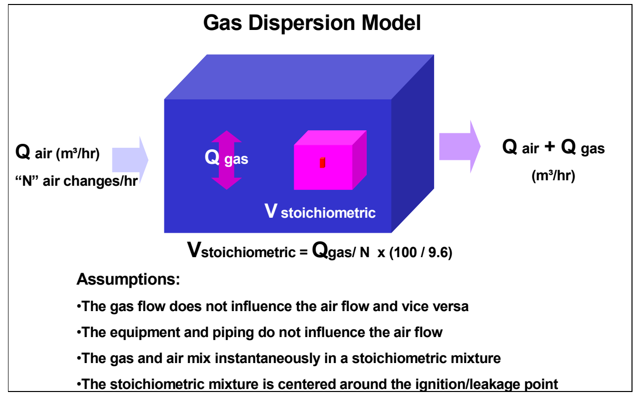


Figure 8: The Gas dispersion model

Ignition Points and Probability. In case of a gas leak and cloud, ignition leading to a gas explosion might occur at various locations within the boundary of the gas cloud. The relative location of the ignition point within the gas cloud determines the origin and effect of the explosion. Sensitivity explosion analyses have been conducted to investigate the influence of the ignition point for a stoichiometric gas cloud of 600 m³ near the manifold or gas liquid separators on the production deck and the launcher or the condensate water separators on the cellar deck. The ignition point for all cases was selected at the manifold. The results of an explosion (in bar overpressure) for the various explosion scenarios on the decks are presented in Figure 9. It clearly demonstrates that the maximum overpressures on the various decks are dictated by a gas explosion and ignition point at the manifold on the production deck. The ignition probability of a gas cloud depends on its size. The bigger the cloud, the more ignition sources could be in the cloud and the more likely ignition becomes. The ignition probability would increase the more ignition sources are engulfed by the gas. In reference [2] a model of the probability of ignition is presented based on historical data. The overall ignition probability of North Sea platforms for small gas leaks is 0.005/year.

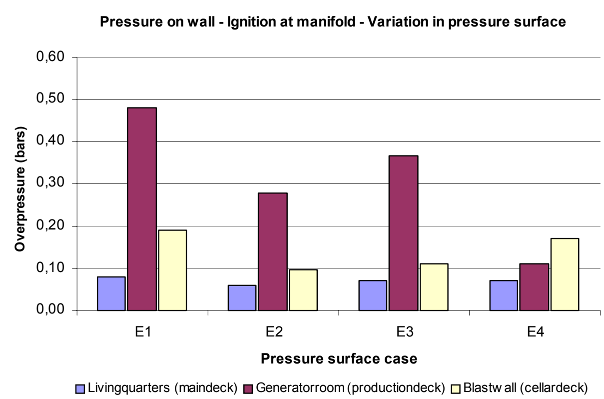


Figure 9: Results of various explosion scenarios

Gas Explosion Analysis.

Modeling. Gas explosion analyses have been carried out using the CFD code AutoReaGas™. AutoReaGas™ is a state of the art 3D computational fluids dynamics computer program for the analysis of combustion in flammable gas mixtures and the subsequent blast effects. It has been extensively validated against various experimental tests, including the large scale tests undertaken as part of the Joint Industry Project on Fire and Blast Engineering for Topside Structures. Gauge points have been modeled equally distributed on the exposed platform and accommodation module including supports and bulkheads in order to determine the over and under pressures as function of time and location. In order to be able to transform geometrical data from AutoCad into a format that can be read by AutoReaGas™ an Excel program has been developed. In the model pipes of 8” and above have been modeled. Both actual and future equipment have been modeled. All the windshields have been modeled as pressure surfaces that disappear at an overpressure of 50 mbar. Detailed modeling is essential since the explosion escalates when the flame front passes objects and thus increases the explosion velocity and (over)pressures.

Explosion Analyses. Simulations have been carried out for ignition in various ignition points and various gas cloud volumes. These simulations yield input data for the structural calculations; specifically overpressure histories and dynamic pressures. The overpressure data are used for the loading on decks, walls and large equipment, whereas dynamic pressures are used for loading on piping and small equipment.

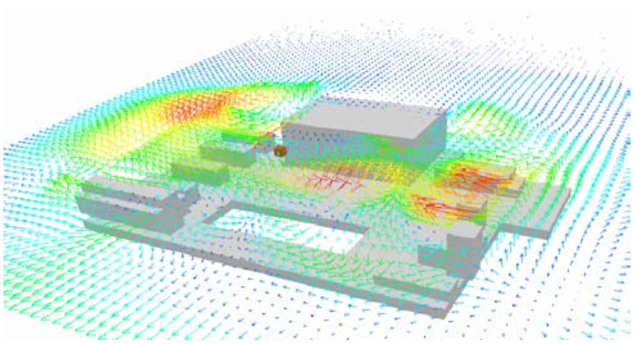


Figure 11: Simulation of an explosion on the main deck

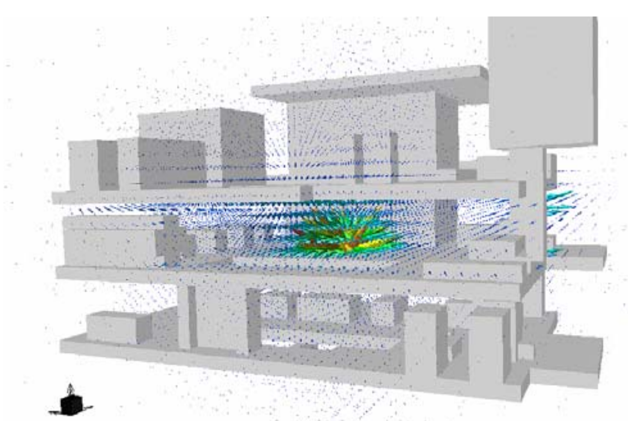


Figure 12: Simulation of an explosion on the production deck

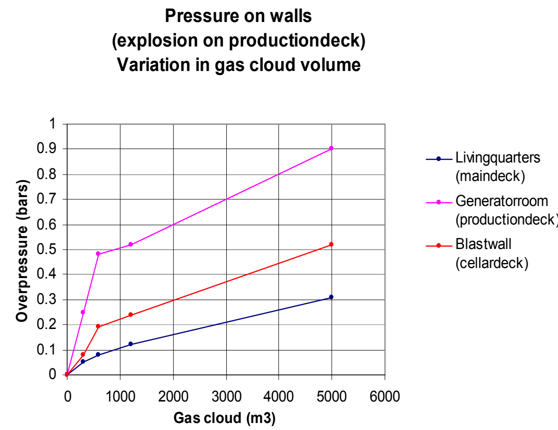


Figure 13: Pressure on walls in relation to gas cloud volume

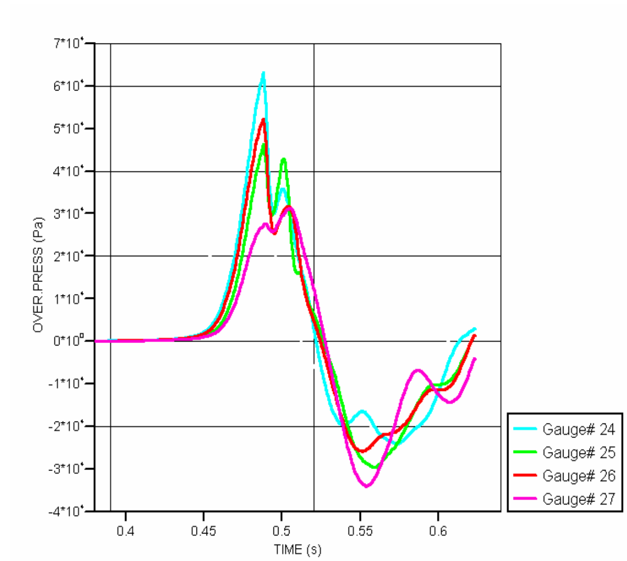


Figure 14: Pressure history plot

Explosion Analyses Results. The explosion on the production deck generates the maximum pressures, also for the main and cellar deck. The maximum pressures are a bilinear function of the gas cloud volume. The theoretical net volume of the production and cellar deck is 5000 m^3. The most probable ALARP gas cloud volume is equal to 1250 m^3 with associated pressures of approximately 150 mbar for the main deck, 550 mbar for the production deck and 250 mbar for the cellar deck. The average pressure pulse duration is in the order of 100 msec, the under pressure following the overpressure is of the same order of magnitude. It is further noticable that the maximum pressures are often elsewhere than near the ignition point, caused by the earlier mentioned turbulence effects when travelling around piping and other objects.

Structural Impact Analysis

Structural Impact Resistance Analysis Method. The scope of the structural impact assessment encompasses the overall and local effect of explosion loading. The overall effect of the explosion loading is checked with regard to the integrity and stability of the platform. In order to meet the design objectives the following checks have been carried out to safeguard protection and evacuation of the platform in an event of gas explosion:

- Integrity and support of the helideck on the living quarters;
- Integrity of the living quarters support to the platform;
- Integrity and support of the deck on the substructure;
- Integrity and foundation of the substructure.

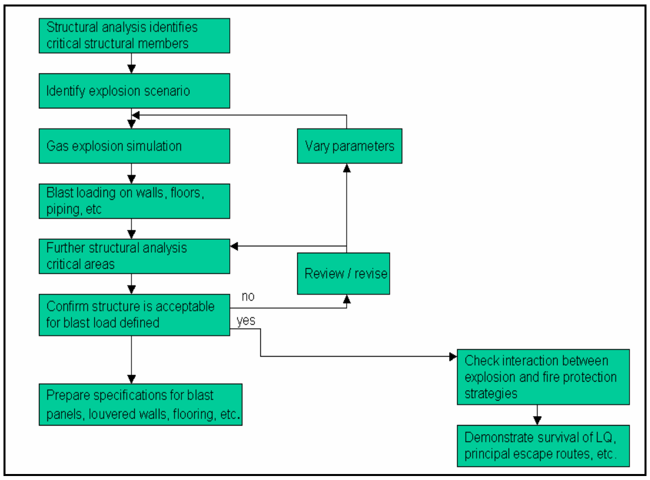
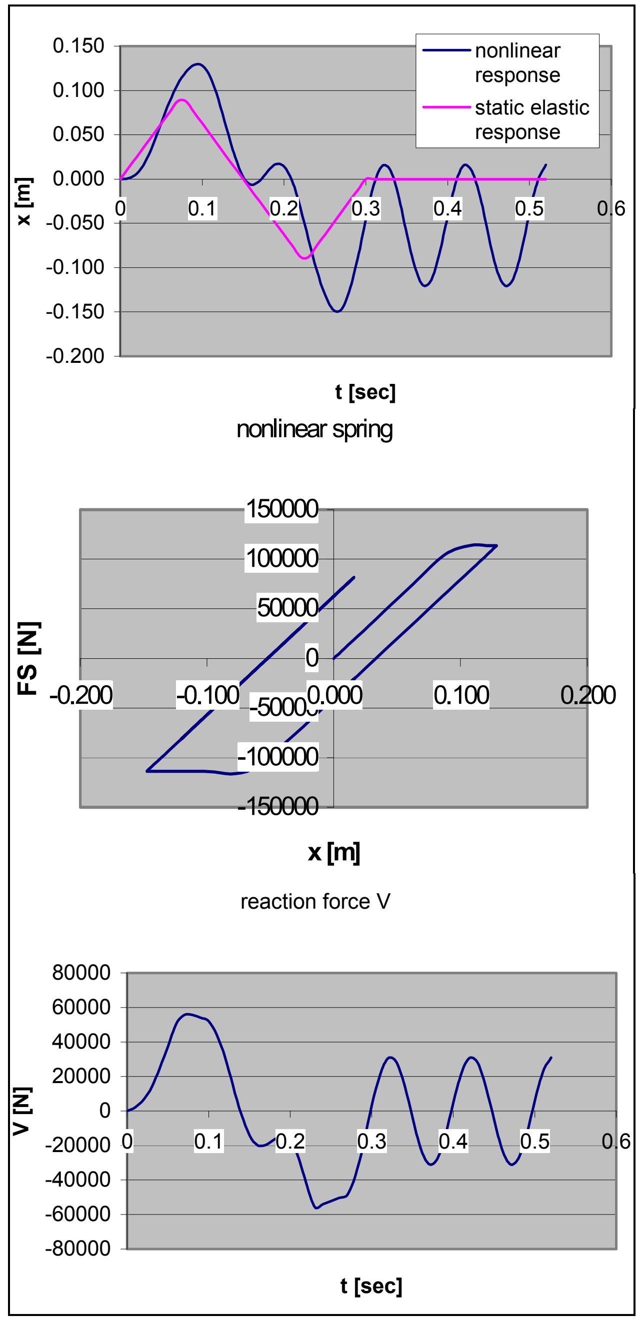


Figure 15: Structural impact resistance analysis method

Blast loadings due to vapour cloud explosions are obtained from the calculations with the program AutoReaGas™. This program provides pressure history plots in selected gauge points. Triangular pulses for both the positive and the negative part of the overpressure can approximate the pressure pulse. Since blast loadings are inherently dynamic, dynamic simulation is required except when the pulse duration is greater than say two times the lowest natural period of the part of the structure to be analysed. As blast loadings constitute a low probability it is not economically justifiable to design all structures as fully elastic. The function of structural elements must therefore be reviewed. The design approach must allow for plastic deformations and possibly large displacements, in such a way that the overall structural integrity is maintained. Structural elements, which are required to stay within the elastic limit, shall be designed to either BS5950 or API-RP2A. Those elements, which may develop plastic deformations, shall be designed to remain within the specified deformation limits. In addition, shear stresses shall comply with elastic design requirements as prescribed in the BS5950 or API-RP2A code. For the design of members subject to tension or bending, strain rate effects may be incorporated to increase the minimum specified yield stress. In the absence of more detailed information an increase of 10% may be taken. The upper limit for the shear stress is 0.5 of the enhanced tensile stress. There is no increase permissible for a member in compression. Once the pressure profiles are available from AutoReaGas™ structural calculations have to be carried out. Two approaches are available for the design of structural steelwork to resist the blast overpressures. These are set out below. The step-by-step integration of these two methods result in an optimum design for blast impact resistance.

Simplified Approach. Using a Rayleigh-Ritz method Biggs [4] derived Single Degree of Freedom (SDF) models for beams and plates under dynamic bending loading, for various boundary conditions and elastic or elastic-plastic behaviour. An Excel program has been developed to carry out the calculations. Figures 16, 17 and 18 depict the dynamic response in displacement as function of time and as spring force as function of displacement. Figure 18 depicts the reaction forces as function of time.



Figures 16, 17 and 18: Dynamic response in displacement

Non Linear Approach. This approach can in principle be used for all blast calculations, but when applied to the whole or a large part of the structure would lead to unacceptable computer time. The approach is used for parts of the structure that cannot be treated with the simplified approach (e.g. membrane action, interacting vibration modes) or in case of doubt regarding assumptions.

Global Integrity Analysis. For the global stiffness analysis of the primary structure, the blast loads are applied as static loads transmitted by blast resisting walls and floors in the following way:

- The wall reactions, calculated in the Excel sheets, are applied as point loads at "hard points" of the appropriate deck level in the SACS model;
- The floor loads, calculated in the Excel sheets, are applied as point loads to the truss chords and spine beams in the SACS model.

In addition the effects of drag forces inducing minor axis bending have been checked separately. It shall also be assumed that there is only a single blast event in any compartment at any one time.

Structural Elements.

Decks. All deck beams, excluding truss chords, but including the stringers and deck plates may be considered secondary and are designed to deform plastically, provided that their deformations do not create the risk of serious escalation of hazardous events or affect the stability of primary steel members.

Trusses. All truss members are considered to be of primary importance to the overall structural integrity of topsides facilities. Therefore, trusses shall be designed elastically, using the maximum reactions transferred by deck and wall panels. Ballistic missile damage to tubular braces can be ignored. The effect of drag forces on truss members is generally insignificant. In case of doubt drag forces may be obtained from the AutoReaGas™ program.

Independent Blast Walls. These walls may be allowed to deform plastically, provided their deformations do not create the risk of serious escalation of hazardous events. Escalation of events can particularly be generated if improper attention is given to the interfaces between blast walls and the main structure; e.g. under blast loading the blast wall will move horizontally, the lower floor downwards and the upper floor upwards, thus generating a potential problem.

Load carrying blast walls. These walls are designed such that after a blast the platform can still withstand a year sea wave loading.

Enclosures. Enclosures protecting Emergency Shut Down Valves (ESDV's) and other critical valves/equipment/fittings are designed elastically so as to ensure the continued functioning of safety systems in an emergency.

Heavy Equipment. The heavy equipment is taken into account as added point masses on plates or beams to count for its effect in the natural frequency.

Equipment and Pipe Supports. Critical equipment and pipe supports (essential to the safe shutdown and evacuation of the platform) are designed elastically. In addition, unless shielded by primary steel girders, they will experience drag forces due to gas velocities generated by the explosion, which could potentially overturn the equipment concerned, leading to escalation of hazardous events. Therefore, such supports are reinforced to prevent overturning.

Hatches. The hatches are checked with respect to ballistic effects due to blast; in this case special clamps were to be applied to prevent hatches coming out of their support. The vertical upward movement of one of the hatches is depicted in Figure 19.

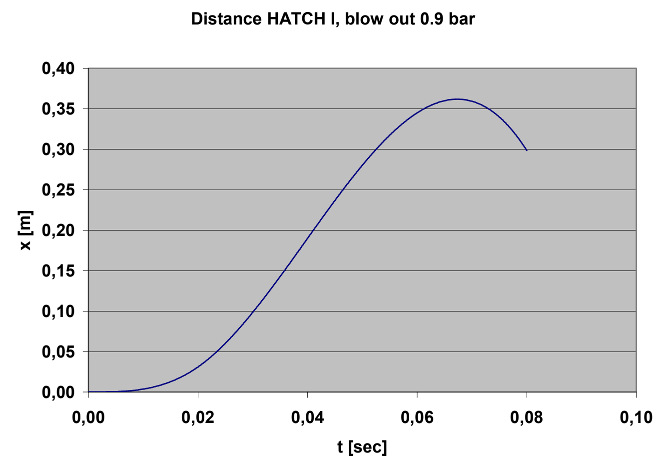


Figure 19: Upward movement of one of the hatches

Conclusions and Recommendations

In order to get optimal quality control, the gas dispersion, gas explosion and structural impact analyses should be carried out by an integrated team, securing optimal exhange of information between the disciplines involved. Most likely gas cloud scenarios should be used. Piping and equipment play an important role in the pressure build up. The explosions on the production deck produce the largests pressures, also on main and cellar deck. Underpressures may not be neglected and should be accounted for in the structural analysis. Typical pressure pulse duration in this case is 100 msec.

Nomenclature

ATEX	*Atmosphères Explosives (European Legislation)*
HIPPS	*High Integrity Pressure Protection System*
$P_{air\ changes}$	*Probability of air changes*
$P_{explosion}$	*Probability of explosion*
$P_{ignition}$	*Probability of igntion*
$P_{gas\ leak}$	*Gas release frequencies*
Q_{air}	*Air flow* $[m^3/h]$
Q_{gas}	*Gas flow* $[m^3/h]$
$V_{stoichiometric}$	*Stoichiometric volume* $[m^3]$

References

[1] Directive 94/9/EC, "On the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres", European Parliament and the Council, Brussels, March 23, 1994

[2] *Upgraded Guidance For Fire And Explosion Hazards*, UKPOOA/Health and Safety Consortium, London, 2002
[3] *Hydrocarbon Leak and Ignition data*, Report No. **11.4/180**, E & P Forum, London, 1992
[4] Biggs, J.M., *Introduction to Structural Dynamics*, 1964, McGraw-Hill Book Company, New York