BLAST AND FIRE ENGINEERING PROJECT FOR TOPSIDE STRUCTURES PHASE 2

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Engineers currently have difficulty in designing against fire and explosion hazards because the loading associated with these accidental events is ill-defined. The Blast and Fire Engineering Project - Phase 2 is performing a series of explosion and fire tests to collect data on the loading associated with full scale hydrocarbon explosions, unconfined hydrocarbon jet fires and confined hydrocarbon pool and jet fires. This data is being used to evaluate and validate computer models that are currently used to predict offshore fires and explosions. In addition the information from this project will enable the *Interim Guidance Notes for the design of topside structures against exposion and fire* published by the Steel Construction Institute to be updated.

BACKGROUND - DESIGNING FOR ILL-DEFINED ACCIDENTAL LOADS

Are the hazards ill-defined?

Recent research has greatly developed the understanding of offshore hydrocarbon explosion and fire hazards and associated loads. This has led to the refinement of predictive models that are commonly used as part of hazard consequence assessment. In many ways, the development of these predictive models is the basis of information transfer from the research community to those working on current design projects. The confidence levels applied to the predictions of these models is a good indicator of how well the accidental loads can be defined.

It is often asked "what confidence limits should be applied to explosion and fire loading models?". During informal discussions between experts, the confidence limits associated with such models is debated. Some experts have suggested only a 10% error band need be applied to these loading assessments. The figure of 10% is one often heard but the origin of this figure is unknown. Other documented comparisons have shown a much greater scatter between current predictive models, unfortunately no-one knows how accurate these predictive models are.

The Blast and Fire Engineering Project for Topside Structures - Phase 2 is the first programme of experimental research that will perform full-scale explosion and fire tests. Until the results of these tests are available no-one can confidently predict what the results of performing experiments at full-scale will be. However it is interesting to note from previous research, that the scale at which experimental work is performed has increased, the calculated loads from re-calibrated models have also increased.

What is current design practice?

When considering how well an accidental load is defined it is worth assessing the consequence of an error in prediction. If the intensity of a fire is under-predicted by 10% this may cause a small decrease in structure or plant survival time. This is obviously critical if the maximum survival time is required (e.g. for evacuation), but often a decrease in survival time from an hour, to say 50 minutes, may not be critical. In comparison a 10% under-prediction in an explosion load could be the difference between survival or failure. Therefore, the possible consequences of an ill-defined explosion load will be far greater than for a comparable fire load.

In designing offshore installations many project teams do not consider explosion and fire hazards adequately at the various stages in design. Appropriate explosion and fire assessment, if carried out, is often left until a late stage in the design process, when the position of most structure and plant is all-ready determined and fixed. Unfortunately, the frequent result is the identification of a problem which cannot easily be rectified.

Other design teams recognise the importance of considering hazards during the whole design process and consider the effects of their actions on hazards loading from an early stage. Nevertheless, it is still common for an early analysis to be performed with only large structure and plant modelled, resulting in reduced accuracy (as at this stage this is the only equipment that has been positioned). As further analysis is performed and the location of more structure and pipework is detailed, large changes in predictions may occur, frequently resulting in an increase in predicted overpressure and problems in quantifying the location and characteristics of fires.

Expert opinion and possible solutions

One of the most common questions experts in the field of explosion and fires are asked is "What loads should I design for?". Unfortunately, the experts are unable to give an answer to this question for several reasons:

- Explosions and fires are very specific to each platform, each having different levels of inventory, confinement and congestion.
- Even on a single platform other variables such as ignition location, fuel type and release conditions have significant effects.
- Most importantly the experts cannot confidently predict full-scale explosion and fire loads, i.e. the accidental loading is ill-defined.

Nevertheless, the experts do have some suggestions that may lessen the problems encountered during design:

- consider "representative" detail at concept stage,
- follow good design principles,
- design for strength rather than to a calculated explosion or fire load,
- keep a safe "gap" between load and resistance,
- possibly design for controlled collapse.

Implementing solutions

The first suggestion of considering "representative" detail at concept stage is perhaps the easiest to implement. A multi-disciplinary approach involving process, structural and risk disciplines would benefit the design of the topside system.

However, the above solution does not address the fundamental problem that the accuracy of the prediction is unknown.

'Good design principles' suggest that if a modification that improves explosion or fire performance is cheap and easy then make it. In theory this sounds like an obvious and sensible statement, however the practical ramifications are not always as straight forward. Experts emphasize designing for strength and not to a load value, keeping a safe gap between 'load' and 'resistance'. The problems associated with fulfilling this advice are those inherent with all 'goal-setting' legislation. It is "easier" to design to a specific value. When designing for strength constant assessment of modifications is required to compare strength improvements with other factors (e.g. cost, time, weight).

In many situations a design solution can make allowances for additional strength to be added at a later stage (if required). This is perhaps an easier and more 'practical' approach than designing for maximum strength.

There is still a lack of sufficient understanding and consideration of accidental loadings during design. Many of the people who are responsible for making decisions which greatly affect accidental loads (e.g. process layout designers, concept design engineers) do not fully appreciate the effect of their actions on them.

The results of full-scale testing from Phase 2 will enable narrower confidence limits to be applied on the predictions originating from consequence models. This will allow calibration of the models and therewith substantially increase the confidence in prediction of hazard consequences, hence removing ill-defined accidental loads from the design process.

THE PHASE 2 PROJECT

The Blast and Fire Engineering Project for Topside Structures - Phase 2 is a Joint Industry Project which aims to obtain data on the loading associated with full-scale confined and unconfined jet fires, pool fires and explosions.

In January 1992 the Steel Construction Institute (SCI) issued a proposal to mark the official launch of Phase 2. By the end of April 1993 positive pledges of support had been received from 11 Participants:

British Gas E & P
BP
Elf Enterprise Caledonia Limited
Enterprise Oil plc
UK HSE
Mobil North Sea Ltd
Norsk Hydro A.S.
Saga Petroleum Ltd
Shell UK Ltd
Statoil
Texaco Britain Ltd

A meeting of these 11 Participants was held on the 24th May 1993 to agree a prioritised scope and to discuss on what basis the project should proceed. A number of key decisions were made:

- The project should commence as soon as possible. The scope of the project should be agreed on the basis of 11 Participants financing the project (£3,750,064). As other Participants joined the project additional work would be agreed by the Participants Committee.

- It was agreed that the project should include work on both explosions and fires. The comparison and assessment of hazard characterisation tools should also form part of the scope.

- The full scale explosion test programme should be carried out in as large a volume as possible, be filled with realistic levels and details of equipment, and should be able to resist a pressure of 4 bar g.

- The fire test programme should be prioritised with emphasis being placed on investigating the characteristics of confined condensate fires and unconfined two phase crude/methane fires.

Based on these key decisions, and subsequent discussions with Participants and Testing Contractors, a prioritised scope was agreed which forms the current project.

The project consists of three main parts detailed in the following sections.

CORE TEST PROGRAMME

Explosion Loading and Mitigation Core Test Programme

The core programme consists of twelve full scale explosion experiments performed at two different geometric configurations. the experimental programme includes the study of the variation of obstacle density, confinement, configuration and ignition position, together with the effect on explosions overpressures of water deluge.

The design of the test rig (Figure 1) was based on the assumptions of versatility and that the maximum potential overpressure will be 4 bar g.

The main steel frame of the rig consists of a uniform grid of members creating a framework structure of 4m cubes. The available funds for the core explosion programme has allowed a test rig of up to 8m high, 12m wide and 28m long to be constructed. Using this form of construction, the test rig will have 16 internal vertical steel columns which will reduce the span of the 12m long horizontal steel beams which support the testing rig roof. Each column is joined to adjacent columns at mid-height by the horizontal structural members. Panels are fitted to the outer edges of the framework to form the boundary conditions.

The test rig has been built at the British Gas Spadeadam Test Site in Cumbria. The erection progressed rapidly and was completed in a 2.5 week period. The excavation for the foundations was 2m deep and has been filled with concrete (some of which is reinforced). The large foundations are necessary to ensure there is sufficient weight to resist the potentially large lifting and overturning forces generated by the explosion. The concrete for the foundations was poured in three segments, the first of which was poured on the 10th December 1994. Over 400m^3 of concrete was poured over a 12 hour period and required the contents of over 80 ready-mix concrete trucks.

The blast panels which form the walls of the rig were delivered to site once the main steel frame was erected. Due to erection tolerances the panels were delivered to site undrilled. They were positioned on the rig and marked-up before being drilled on site. Figure 2 shows the test rig with most of the blast panels in-situ, the rest of the panels are being left off to allow installation of the obstacles (Figure 3).

Construction of the test rig has progressed smoothly, with concurrent activities preparing a control cabin, installing instrumentation cabling and clearing the area around the test rig. The construction of the rig was completed by February 1995 which was followed by the installation and checking of instrumentation before the first explosion test which was performed in May 1995.

Confined Jet and Pool Fires (CF)

This test programme is being conducted by SINTEF (Norway) using their confined fire test rig, located in the test hall at Tiller near Trondheim in Norway. The rig consists of external corrugated steel elements and internal thin stainless steel sheets separated by 150mm ceramic fibre insulation. The inner steel skin acts as a heat shield and protects the insulation from water during the deluged fire tests.

The rig is of modular construction, enabling the rig dimensions to be varied. The rig size for the tests is 6m x 6m x 13m. The modular nature of the rig enables different vent sizes to be introduced into the walls and roof at any location.

A series of propane and condensate jet and pool fires are being investigated to address the effect of confinement on the characteristics and burn location/geometry of the fires. The condensate jet fire tests are being performed at up to 15 bar g release pressures. A maximum flow rate of fuel (Xkg/s see below) is being determined so as to limit any external flame sizes to 18m high and 40 MW energy output. This is necessary to prevent damage to the actual test hall.

The indicative core programme consists of the following test cases:

CASE CF/1: Prepare, commission and function test the 6m x 6m x 13m module with 15 bar g condensate jet fires and condensate pool fires. Determine the maximum jet fire fuel flow rate (X kg/s).

Calculate the optimum ventilation condition (CVA) to give the highest heat fluxes within the module at a flow rate of X kg/s for both pool and jet fires.

Test the system to verify the flow rates, flame extension and ventilation calculations. Optimise the jet position so that it does not spray directly out of the module when the walls are removed for well ventilated tests. Carry out jet fire tests at X kg/s at up to 15 bar g under the following ventilation conditions:

I. Optimum ventilation condition (CVA)
ii. Ventilation controlled conditions (<CVA)
iii. Well ventilated condition (>CVA)
iv. Very well ventilated condition (> >CVA)

Carry out pool fire tests at X kg/s under four ventilation conditions i. to iv.

CASE CF/2: Carry out the jet and pool tests described in Case F3/1; at ventilation conditions i, ii, iii or iv and including general area medium velocity deluge at 12.2 litres/min/m^2 and 2m nozzle spacing applied at a predefined time after ignition.

CASE CF/3: Prepare, commission and function test a jet impinging onto a cylindrical target placed centrally within the module. Prepare and commission a similar arrangement with a pool fire directly beneath the target. Carry out jet and pool fire tests in two of the four ventilation conditions (i and iii or iv). Measure the flame characteristics and the module and target responses.

CASE CF/4: As Case CF/3 tests but with the deluge system operating as described in Case CF/2.

CASE CF/9: As for previous cases but with two different orientation of the jet under two different ventilation conditions as in i or iii or iv.

A number of confined fire tests have now been performed. The fires, both pool and jet, have provided valuable data for the project. The Phase 2 Fire Working Group (FWG) are currently analysing the results of the experiments.

Unconfined Jet Fires (UNCF)

The core test programme relating to unconfined jet fires aims to study and quantify the physical, thermal and liquid rain out characteristics of unconfined large scale horizontal jet fires involving crude, crude/natural gas, condensate, and condensate/natural gas. These tests are being conducted at full scale using the British Gas unconfined jet fire rig at Spadeadam (UK).

The indicative core programme consists of the following cases:

CASE UNCF/1: Prepare, commission and function test a jet fire facility discharging 5kg/s stable crude oil flow rate with release pressures of 2, 7 and 20 bar g. Carry out flame crude oil tests at the pressure and flow rate required above.

CASE UNCF/2: Prepare, commission and function test a 0.9m diameter tubular target for use with the crude oil jet fire facility and positioned at various impingement distances. Carry out impinging crude oil tests at 5kg/s at a 7 bar g release pressure. Measure the fire characteristics and target response.

CASE UNCF/3: Modify, commission and function test the crude oil jet fire facility to allow simultaneous release of natural gas and crude oil through adjacent orifices. Carry out free flame tests with 2kg/s of natural gas and 3kg/s of crude oil with release pressures of 2, 7 and 20 bar g.

CASE UNCF/4: Prepare and function test the target (as in Case UNCF/2) with the composite natural gas/crude oil jet fire. Carry out impingement tests as in Case UNCF/2.

During November 1994 British Gas performed a series of commissioning tests which enabled them to derive the test procedures for monitoring the crude oil and 2-phase jet fires. The first official Phase 2 unconfined jet fire test was performed in May 1995 (Figure 4).

ASSESSMENT OF EXPLOSION AND FIRE TECHNIQUES

The characterisation of hydrocarbon explosions and fires as part of design or safety assessment requires the use of appropriate prediction techniques. These techniques vary in their level of sophistication and scientific basis. Some are only suitable for screening and conceptual design whilst others are used in detailed design.

The development of these techniques has been based on theoretical research, various small to medium scale experimental work programmes or a combination of both. Their ability to predict the development of fires and explosions at full scale and in realistic configurations has not therefore been proven.

In Phase 2, these techniques are being compared against each other and against the Phase 2 full scale test data. The scope is as follows:

a) Modellers undertake predictions of the fire and explosion experimental scenarios forming Phase 2.

b) The results from (a) have been compared and variations identified and assessed.

c) Activities (a) and (b) were completed before the start of testing.

d) Selective full scale experimental results will be made available to the Modellers who have participated in the pretesting predictions so that these techniques may be re-calibrated with the new data. The extent of re-calibration will be an indication of the confidence that can be applied to such predictions when made beyond the range of data against which they have been validated. The results from all the techniques will be compared with the experimental results.

e) To assess the re-calibrated techniques, the Modellers will be asked to apply their techniques either to re-model an experiment for which test data were not released, or to a new configuration. The results from this exercise for all the techniques will be compared.

DESIGN GUIDANCE, REPORTING AND DELIVERABLES

The preparation of guidance commenced early in the project schedule. The methodology is as follows:

a) Update the Phase 1 work (which was completed in November 1991) on the assessment of information on explosion and fire loading and active mitigation systems. This requires a review of work completed, on-going or planned for the period November 1991 to September 1995.

b) Create a database of all available experimental results (at all scales) which are appropriate to explosion and fire loading.

c) Input information and data generated from Phase 2 into this reporting activity.

d) Carry out an assessment of all data collected in (b) and (c) above.

e) Prepare and issue the design guidance document as an updated edition of the 'Interim Guidance Notes for the Design and Protection of Topside Structures against Explosion and Fire', the first edition of which was issued at the end of Phase 1.

The preparation of the design guidance will be the responsibility of the Project Manager. Involvement of Participants will be actively encouraged to assist with and comment on this work throughout the project. SCI engineering support and industry experts/consultants will also be called upon to provide input into this activity.

The design guidance will cover the following:

Hydrocarbon explosion loading and mitigation

a) Description of the explosion phenomena.

b) Appraisal of available or new techniques for predicting explosion overpressures. Limitations, applications and confidence levels will be defined. The assessment of a number of techniques is necessary due to the wide range which is available and used by the offshore industry.

c) Guidance on how to mitigate explosion overpressures by the use of appropriate changes in equipment detail and confinement conditions.

d) Guidance on the use of water deluge active mitigation techniques.

Hydrocarbon fire loading and mitigation

a) Description of hydrocarbon fires in unconfined, partially confined and confined spaces.

b) Critique of available or new methods, models and techniques for screening or prediction fire development and thermal loading. Limitations, applications and confidence levels will be assessed.

c) Guidance on thermal loads and the effect of confinement on the severity and location of fires.

d) Guidance on the use of water deluge active mitigation techniques.

SUMMARY AND CONCLUSIONS

After several years of careful planning the Phase 2 project is progressing rapidly. The explosion test programme is underway while both British Gas and SINTEF have performed fire tests. This work will continue for over a year with the fire tests finishing in 1995 and the explosion tests being performed between May 1995 and January 1996.

The first tests have shown that Phase 2 is generating high quality useable data at full-scale. Initial analysis of results indicates that the project should be able to produce positive information and guidance to assist engineers in designing against fire and explosion hazards. The fire and explosion modelling exercises are progressing and will, for the first time, allow models to be calibrated and validated against full-scale data.

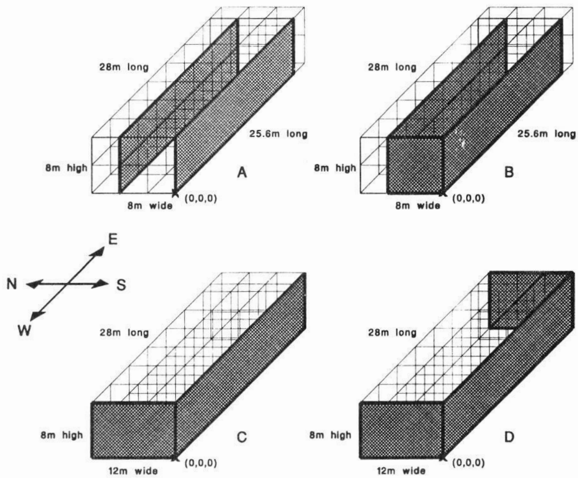

Figure 1: Explosion Test Rig Configurations.

Figure 2: Completed Steelwork and Installed Wall Panels.

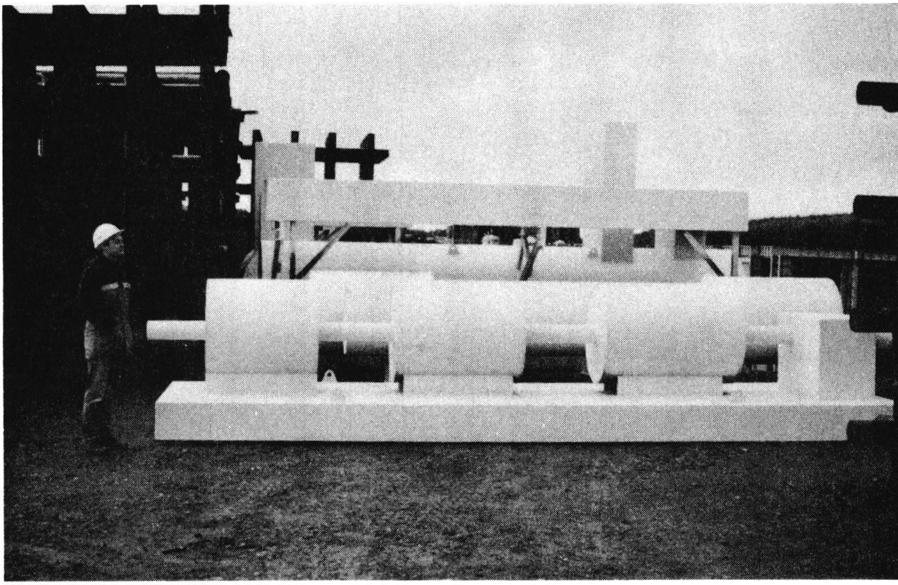

Figure 3: Large sized obstacles.

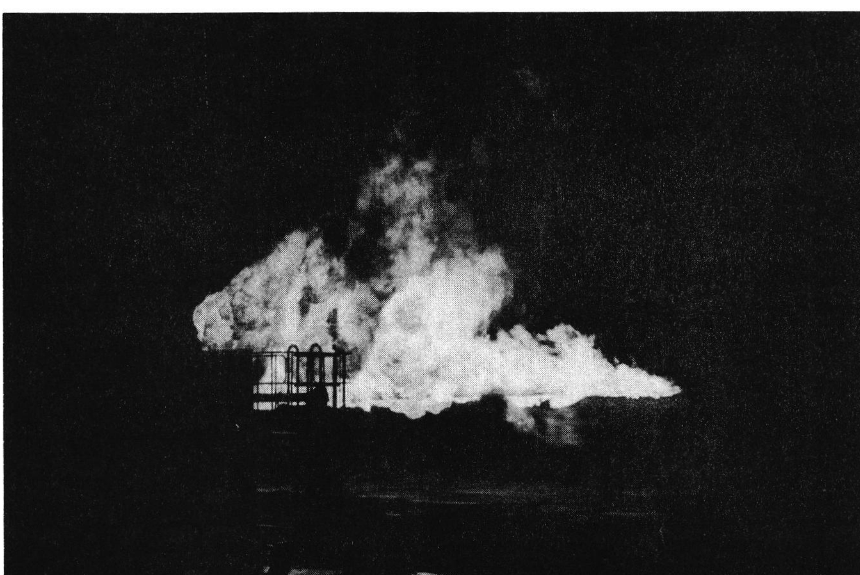

Figure 4: Unconfined Crude Oil Jet Fire Test.