REPORT FOR CONCEPT DEVELOPMENT, DESIGN AND TESTING PROCEEDURES,
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Submitted to

Research Partnership to Secure Energy of America (RPSEA)
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1. Introduction

Designing topsides structures to withstand credible explosion events and to prevent the potential devastating phenomena of deflagration to detonation transitions (DDT) is an essential part of the route towards inherently safer designs for Gulf of Mexico (GOM) drilling and production facilities. Two main factors are currently inhibiting inherently safer designs: (1) lack of detailed geometry information in the early design phase, which, when congestion due to small items is not integrated into the model when performing explosion studies, the design blast loads will be severely underestimated and (2) no adequate tools to predict the potential risks of DDT at these facilities, where the consequences of DDTs can be orders of magnitude larger than typical deflagrations.

This report will cover both the large scale testing that will make up the DDT model validation and the CFD GOM ACM development procedures.

2. Large Scale Testing

2.1. Background

As part of the bid and award process, the outlined objectives were to (1) perform large-scale tests to assess DDT onset and obtain model validation data at scales and geometries relevant to GOM UDW structures and (2) develop ACM for GOM top-side structure congestion. Large scale testing can prove to be a challenging undertaking. The time and financial commitments, not to mention safety concerns, to undertake testing of this magnitude limit the uncertainties that can be present at the time of testing. This section will attempt to outline a specific plan to ensure our project objectives are met beginning with background research through physical testing.

A more specific outline of the intended outcomes from this large scale testing would be to achieve DDT for three different fuels at three different congestion levels. A goal for this testing would be to achieve DDT with stoichiometric ethylene as a fuel for a “low” congestion module, DDT with stoichiometric propane for a “medium” congested module, and hopefully DDT with stoichiometric methane in a “high” congestion module.

2.2. Literature Review

Since there is a limited amount of literature on previous large scale testing to evaluate DDT, it is necessary to review and understand the previous work in order to ensure our project objectives can be met in an effective and efficient manner.

To begin the large scale testing plan, reports will be reviewed from previously performed experiments. The focus of this preliminary study will be on experiments performed by (1) the Health and Safety Executive, specifically their BFETS experiments, (2) British Gas Research & Technology, more specifically their 45m rig, (3) British Gas and their Project MERGE, and (4) Shell Global Solutions and their rig experiments performed with ethane.

At the time of this report, the research that has proved to be most intriguing is the tests conducted by British Gas at their Midlands Research Station in 1985. This series of tests resulted in deflagrations that were on the cusp of transitioning to detonation. Through discussions with personnel that were present at the testing in 1985 and the published information, we believe that by slightly raising the congestion level and/or the length of the rig we will achieve DDT for stoichiometric propane. This is significant because it will provide a baseline point at the minimum congestion and rig dimensions that will allow for DDT.

2.3. FLACS CFD Validation

GexCon’s commercially available FLACS software has been extensively validated against numerous experiments. As part of our commitment to fully understand the likely results of the large scale testing in advance of execution, we will reevaluate the validation process against the experiments of interest identified in the literature review. Many of these experiments have been previously modeled prior to any commercial release of the FLACS package. This internal investigation will ensure our understanding of the validation process and identify any weaknesses that might exist in the code with respect to the DDT type experiments we will be performing at a large scale.

2.4. Rig Design

This phase will involve both computational experimentation and CAD design work for the proposed final geometry. This rig should be robust enough to withstand the anticipated DDT overpressures and drag forces, yet versatile enough to easily change the geometry configuration and congestion levels.

To begin this portion of the project, FLACS CFD numerical experiments will be performed. The focus of this study will be on understanding current measures of congestion. Currently, congestion is generally reported as a (1) packing density (L/V), calculated as total length of pipe (L) in a given volume (V), (2) volume blockage ratio (V_{obs}/V), total volume of pipes (V_{obs}) obstructing the flow within a given volume (V), or (3) surface area to volume ratio (A_s/V), the cross-sectional area of pipes (A_s) obstructing the flow in a given volume (V). The FLACS CFD experiments will begin to estimate the potential overpressures and onset of DDT by varying pipe diameter and orientation and comparing the calculated overpressures to the different "typical" congestion measures. This will allow us to both study overpressure effects from varying pipe size, orientation, spacing along both rows and columns, alternating pipe sizes and non-uniform congestion layouts. In addition, numerical simulations will evaluate the total footprint dimensions of the rig to ensure that any resulting DDT from the large scale experiments can be conducted safely. As of the time of this report, approximately 1000-1200 CFD simulations have been performed to evaluate the parameters of interest.

In conjunction with the FLACS experiments, engineering design for physical rig will be conducted. This design will take into account: the results from the literature search, the results from the CFD experiments and input from the GexCon capital modules. As mentioned earlier, the final rig design will be maintained as modular, such that the congestion levels will be able to be easily modified to accommodate different fuel types. Some final congestion level design discussions have resulted in Figure 1. The modules are 12-ft cubes.

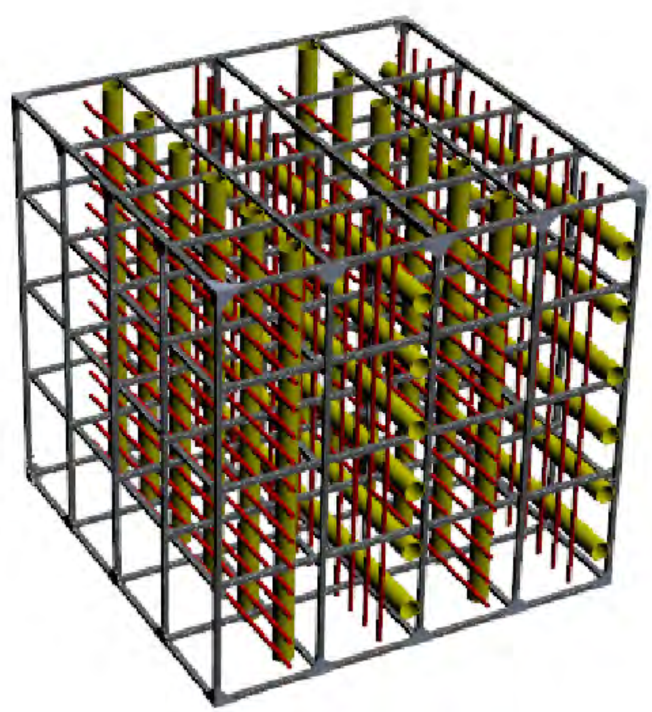

Figure 1: Final congestion rig module unit design

2.5. Test Site Facility Modifications

To accommodate the large-scale tests SRI is tailoring a test area at their Corral Hollow Experiment Site (CHES) near Tracy, California. This will involve SRI capital improvements including modifications to an access road in order to transport the rig modules to and from the test pad as well as modification of a concrete test pad. The road modifications include widening the road, placing a gravel base, paving, and providing drainage as necessary. Additional modifications will involve gas handling and instrumentation infrastructure.

2.6. Proposed Large Scale Measurements

The measurements needed to adequately characterize the large-scale experiments include stoichiometry measurements, flame speed, and overpressure. It is crucial to have an accurate measurement of the gas concentration and homogeneity within the containment envelope prior to ignition. Flammable gas will be introduced at one or more locations and mixing will be performed using induction fans located within the envelope. The proposed instrumentation to measure the gas concentration is to use an IR sensing system such as the Servomex 4200 multi-channel suction system. A single measurement unit will be placed in a hardened structure just outside the test area with the four independent sample lines placed at strategic locations within the envelope. The response time is dependent on the length of the sample line and the sampling flow speeds and may take 15 to 20 seconds for a stable measurement, but this should not be an issue for these experiments.

We will acquire ionization pins (e.g. Dynasen CA-1040) or microsecond responding thermocouples (Medtherm TCS) to detect the position of the ionized flame front during deflagration or detonation. We have used this type of chronography successfully many times to make this measurement. In addition we will use up to four Phantom v7.1 and Phantom v7.2 high-speed video cameras to monitor the deflagration reaction front position to determine the flame speed. Overall video coverage of the experiments will be provided using high-definition digital video cameras, one recording in the visible light spectrum and one in the infrared to cover gas-explosion experiments.

Overpressure measurements will be made using either piezoelectric or piezoresitive blast sensors such as those made by PCB Piezotronics (e.g. 112M343 or model 113) or Kulite (ETS). We have developed specialized approaches to minimize pressure sensitivity to nuisance thermal and ground shock inputs and will apply that to these experiments. An array of digital transient recorders (e.g. Nicolet Odyssey 14-bit or Nicolet Pro and 440 series 12-bit) will be used to capture and retain the measurement data.

We will monitor weather conditions during each experiment using up to two weather stations located close to the test facility. We will record parameters such as air temperature, wind velocity/direction, barometric pressure, humidity, and rain.

2.7. Proposed Large Scale Test Matrix

Three fuels will be used for the large scale experiments, methane, propane and ethylene. Three general congestion levels will be used, “low”, “medium”, and “high”. These congestion levels will be designed such that stoichiometric mixtures of ethylene, propane and methane detonate at the “low”, “medium” and “high” congestion levels respectively. These experiments will be conducted at various fuel concentrations ranging from fuel-lean through stoichiometric to fuel-rich. The target concentrations have yet to be defined, but will be evaluated through numerical simulation prior to execution. GexCon’s preliminary proposed test matrix can be found below as Figure 2. This is still under discussion with the WPG and will be finalized before the firsts tests are scheduled to begin.

In addition, a series of tests will be conducted to evaluate the effectiveness of mitigation measures, such as water deluge or solid inhibitors, on the reduction of explosion consequences at large scale. It is anticipated that at least one cost-share partner will participate with their own solid inhibitor design.

		Low Congestion		Med Congestion		High Congestion	
		Poss	Selected	Poss	Selected	Poss	Selected
Methane	lean	x		x		x	
	stoich	x		x	x	x	x*
	rich	x		x		x	
Propane	lean	x		x	x	x	x
	stoich	x	x	x	x*	x	
	rich	x		x	x	x	x
Ethylene	lean	x	x	x	x	x	
	stoich	x	x*	x		x	
	rich	x	x	x	x	x	

Figure 2: Proposed test matrix. Tests marked with an asterisk will be performed twice.

3. ACM Development

3.1. Background

As it was outlined in the original proposal submitted to RPSEA, this portion of the study will develop the ACM specifically for GOM offshore drilling structures and production facilities. We will provide numerical test results for a full test matrix of GOM topside structures in fully detailed design, including explosion pressure and ventilation as a function of object density and design detail. From early-design CAD geometry models we will gradually implement anticipated congestion to evaluate explosion blast loads, then compare results with detailed design results.

3.2. Geometry Models

The most important aspect of this portion of the study will be obtaining as-built geometries of facilities in use in the GOM. It will be necessary that these models represent the actual conditions on the offshore facilities as possible. This data will come from the cost-share partners as part of their agreement. Our initial target for will be approximately 4 platforms, if possible, from each of four partners for an approximate total of 16 as-built platforms. In order to ensure the accuracy of these models, we will request up-to-date photographs of the facilities and/or site visits to perform photo documentation. Currently, the project has secured two cost share partners with an expected total of eight platforms. GexCon is in final negotiations with one additional CSP and is in discussions with several other interested parties. We remain optimistic we will be able to obtain all 16 platforms.

3.3. Congestion Counts

After obtaining the as-built models and ensuring they are accurate, we can count the congestion levels of each of the installations. If multiple types of platforms are provided, such as drilling and production platforms, they will be grouped accordingly to document the average, lowest and highest levels of congestion for each installation. The standard L/V, A_s/V and V_{obs}/V congestion parameters will be counted in addition to any new parameters determined to have a better correlation with potential overpressures.

We have had internal discussions about the best way to handle this and the exact methodology to develop adequate tools is still under evaluation. Currently, we are determining the most efficient way to count objects and assign properties to them. This may involve indicator criteria in the FLACS geometry database itself, or it may be more simplistic and only count the object file used for the CFD simulations (which is independent of the geometry database).

3.4. Numerical Experiments

Two different styles of numerical experiments will be conducted. The first one will be to run numerical experiments in a “top-down” approach. Starting with the as-built models, pipes will gradually be removed that are smaller than 2” diameter, then 4” diameter, all the way up to approximately 10” diameter pipes. This will allow us to demonstrate the level of detail necessary in the geometry model to obtain realistic overpressure results.

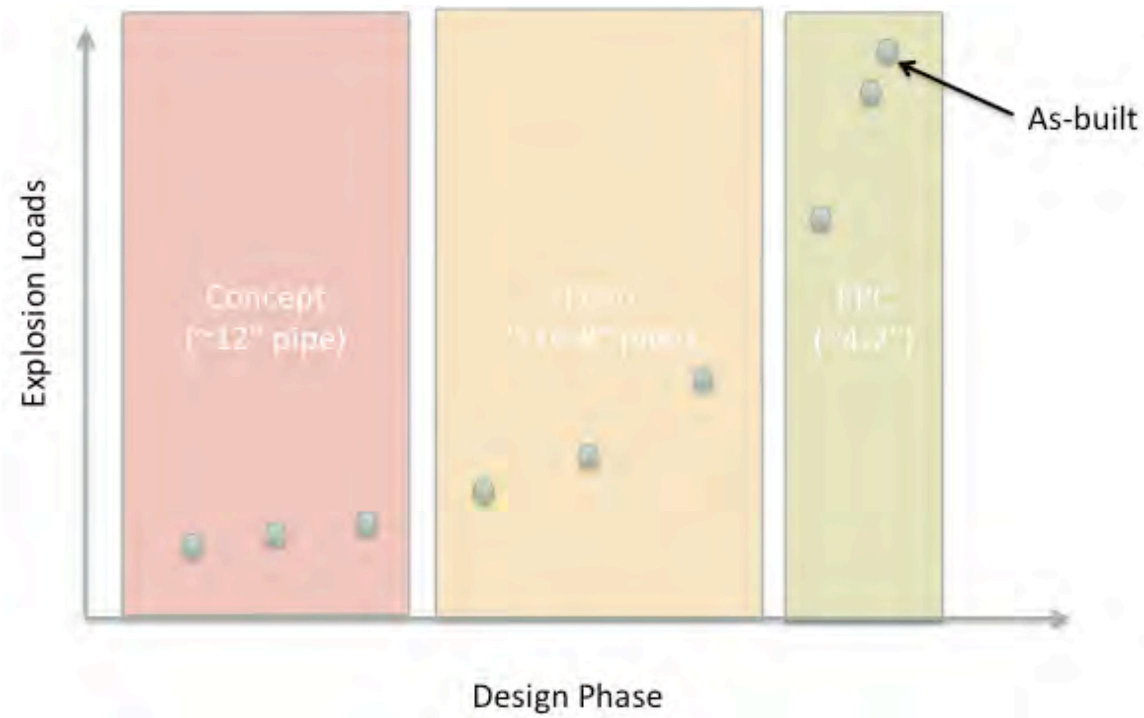

Figure 3: Congestion versus explosion loads exemplar plot

In addition, we will also obtain the same models in early design phase, such as Concept or FEED phase, and we will then populate the geometry with anticipated congestion. This will be the second approach as "bottom-up". In parallel with the first approach, we will re-populate the stripped down models with similar anticipated congestion. Congestion will continue to be added to the models until the maximum overpressures are similar in magnitude to those obtained in the as-built models. From this study, an ACM methodology will be developed that will be specific to GOM offshore facilities as is described next.

For the numerical experiments section, ventilation and explosion simulations will be performed.

3.5. Anticipated Congestion Methodology

Current industry best practice is based on installations in the North Sea, not the GOM. The North Sea platforms are generally exposed to harsher weather conditions and tend to have more confinement than those present in the GOM. With the platforms that we have obtained from the cost-share partners, GexCon will be able to evaluate and compare the AC methodology developed for the North Sea platforms and evaluate its effectiveness and applicability to the GOM installations.

This study will evaluate the use of generic "AC blocks", which are generic building blocks of specific process equipment, such as turbine generators. These "blocks" can be scaled and moved, but already have supporting piping and structure included in them to mimic the geometry in an as-built configuration. These blocks are typically added to geometries in the early design phase (Concept or FEED) to ensure that not only the final congestion levels but its relative distribution (meaning higher congestion around process equipment) are conserved in the model for explosion risk studies.

A large focus of this study will be on the CFD simulations of overpressure. Specific focus will be on the variation of results due to inherent uncertainty in the AC congestion levels. These uncertainties can be due to design changes, modifications or general uncertainties during design phase. For example, how would the explosion overpressures change if the average congestion levels vary by ±10%? Similarly, is there more sensitivity to the explosion consequences if the ±10% uncertainty in congestion was uniquely in the small piping (<2 inches) or larger piping (>10 inches)? This will be studied by continuing to run identical sets of CFD simulations will only geometry changes. The CFD simulation set will be optimized to obtain statistically significant results while running a reasonable amount of simulations.

4. Guidance Document

A final guidance document will be developed that will address both advanced and simplified tools that can be used to determine the necessary parameters to predict if a given installation will be susceptible to DDT. These tools will be based on new correlations regarding the congestion at large scales, and used in early design phase to help ensure inherently safer design of offshore facilities.

In addition, the guidance document will also take into account all of the data obtained in the ACM development section. Guidance will include details regarding the necessary levels of congestion in order to ensure meaningful explosion risk studies in early design phase, where the necessary details are missing from 3D models of the facilities. It is anticipated that this document will be robust enough to provide guidance for the expected congestion levels on different types of platforms, individual modules, specific process areas and geographic location of the installation.

5. Conclusion

Specific test plan and CFD simulation plans are still in development. An outline has been provided to begin their optimization and completion. Cost analyses and lead times are still being evaluated for large scale test facility modification. The ACM evaluation methodology will also be finalized when a set number of platforms are obtained from prospective cost-share partners. This may need to be modified depending upon the types of platforms provided.

A follow-up document, A Roadmap to close the technology gaps, will be issued to supplement the identified gaps present in this report. The Roadmap will also demonstrate that the experimental portion of this project will have no or reduced impact on environment and safety.