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Large Scale Detonation Testing – RPSEA Project Award

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Abstract

As the size of Ultra Deep Water (UDW) facilities increases in the Gulf of Mexico (GOM), designs must consider the potential adverse effects associated with vapor cloud explosions in large congested areas and understand the potential for more devastating deflagration-to-detonation transitions (DDTs) on these facilities. However, there is a lack of data at the large scale to validate the necessary design tools used to predict the risk of DDT. GexCon was awarded Subcontract 12121-6403-01 under the Research Partnership to Secure Energy for America (RPSEA), whereby the objective of this project is to improve inherently safer offshore facility designs. One of the main goals of this research project is to provide large scale DDT explosion data and validate the tools necessary to predict vapor cloud explosions in early design phase. The work will also be used to develop guidance documents and recommended practices to facility owners and designers in order to minimize the potential consequence of explosion incidents.

This paper will present the current updates for the large scale testing being conducted in a newly developed test rig of 51,840 ft^3 (1,459 m^3) gross volume. These tests will involve evaluation of deflagrations and DDTs involving stoichiometric, lean and rich mixtures ethylene, propane and methane. Further phases of the testing will evaluate the effectiveness of other mitigation measures (e.g., water deluge, solid inhibitor) on the explosion consequences. These experiments will be used to validate and further develop industry-accepted CFD tools and more simplified methods in their prediction of DDTs at the large scale including events involving mitigation.

Introduction

A large vapor cloud explosion (VCE) followed by a fire is one of the most dangerous and high-consequence events that can occur on ultra-deepwater (UDW) drilling and other offshore facilities. The Piper Alpha incident in 1988 was one of the most critical turning points in offshore safety, whereby a relatively minor explosion in the compression module escalated to a massive fire that killed 167 people and destroyed the platform (see Figure 1). This incident demonstrated the need to not only understand explosions, but also the importance of avoiding escalating consequences of minor incidents. Despite the Piper Alpha incident being a key driver in explosion research and the development of modern risk assessments for offshore structures, incidents continue to occur as witnessed by the 2010 Deep Water Horizon incident. This event was the result of a minor explosion on an Ultra-Deepwater (UDW) semi-submersible rig escalated into a massive fire that killed 11 crewmen and led to the largest oil spill in US waters (see Figure 2).

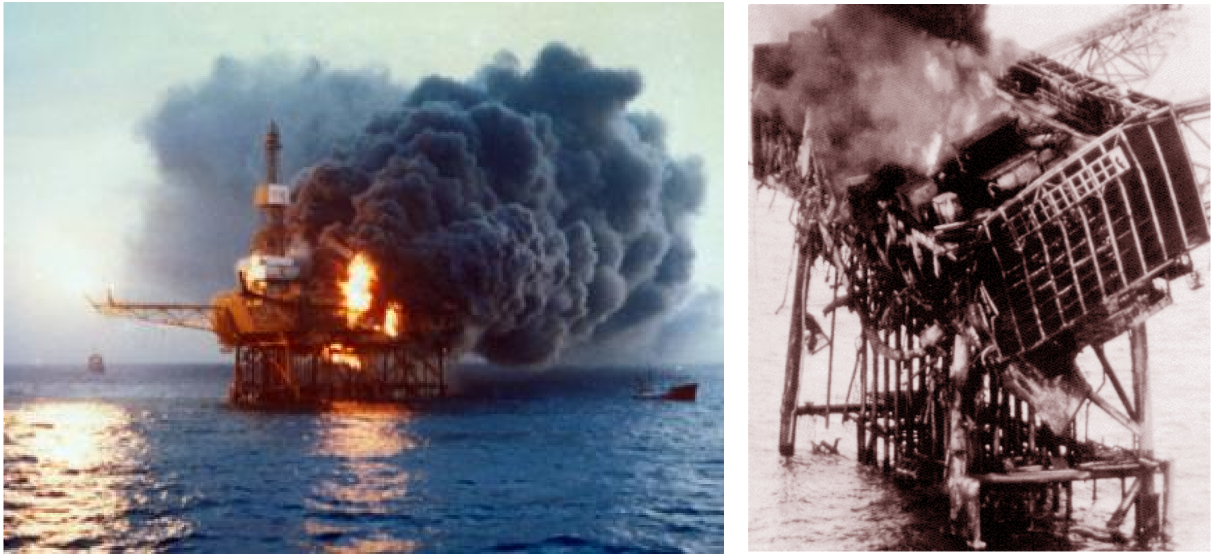


Figure 1: Images of the 1988 explosion and ensuing fire on the Piper Alpha platform

Figure 2: Images of the 2010 explosion and fire on the Deep Water Horizon semi-submersible rig

Designing topside structures to withstand a maximum credible event (MCE) is an essential part of the path toward safer designs. This design philosophy is based on avoiding unacceptable escalation of an MCE to the facility and safety critical equipment. This is especially true as the size of UDW facilities increases in the Gulf of Mexico (GOM). Designs must consider the potential adverse effects associated with vapor cloud explosions in large congested areas and understand the potential for more devastating deflagration-to-detonation transitions (DDTs) on these facilities. Hence, it is critical to understand how a facility's geometry or equipment layout can affect explosion consequences and assist in their mitigation and/or prevention.

While the likelihood of DDTs is lower than deflagrations, they have been identified in some of the most recent large-scale explosion incidents including: 2005 Buncefield explosion, 2009 San Juan explosion, and 2009 Jaipur event. The consequences of DDTs can be orders of magnitude larger than deflagration because they have the ability to self-propagate outside the region of high congestion/confinement. Due to the inability to predict such devastating phenomena on the large scale, owners and designers cannot evaluate installations for risk of DDTs and provide "inherently safer" layout or mitigation measures to significantly reduce or eliminate such hazards.

Therefore, two main factors inhibit inherently safer designs: (1) lack of validated design tools to predict risk of deflagration-to-detonation transition (DDT), where the consequences can be orders of magnitude larger than typical deflagrations (determining under what conditions a DDT can occur and what mitigation measures will work are crucial in calculating MCE for offshore facilities); and (2) lack of detailed geometry information identifying congestion in the early design phase, which results in severe underestimation of design blast loads when not accounted for in explosion studies.

GexCon was awarded Subcontract 12121-6403-01 under the Research Partnership to Secure Energy for America (RPSEA), whereby the objective of this project is to provide tools to help design inherently safer offshore facilities, specifically addressing the technology gaps presented above. The objective of the project is to address the two above mentioned technology gaps by: (1) improving, adapting, and validating the tools necessary to predict MCE early in the design phase of Gulf of Mexico (GOM) UDW facilities and (2) providing guidance and recommended practices to facility owners and designers which, when utilized, will help minimize and design against the consequences of fire/explosion incidents.

In order to achieve such goals, GexCon will perform large-scale experiments to validate DDT onset prediction and active mitigation at scales relevant to GOM UDW structures and develop an anticipated congestion method (ACM) for GOM structures for early, accurate predictions of explosion consequences. These studies will be used to further validate and develop industry-accepted CFD tools and simplified methods, which are currently used to evaluate the consequences of explosions in the oil/gas industry.

Overall Methodology

To facilitate the design of "inherently safer" facilities, we need to predict the maximum credible event (MCE) for vapor cloud explosions and evaluate how design changes affect the possible consequences. Determining whether a deflagration-to-detonation transition (DDT) can occur is imperative for accurate calculation of MCE. Currently, there is a lack of adequate tools that can predict DDT in oil and gas facilities, especially at the large scale that is most common to UDW facilities. To address this problem, GexCon US has teamed with SRI International to further develop and validate the DDT onset prediction capability of GexCon's FLACS CFD package and other analytical tools, and to investigate mitigation techniques that can reduce the consequences of VCEs on UDW facilities through large scale experimental testing. To address the issue of accurate predictions of explosion consequences early in the design phase, we are working to develop an anticipated congestion methodology (ACM) as well as a congestion database for as-built and early phase platforms designed for ultra-deepwater facilities in the Gulf of Mexico. GexCon developed the original anticipated congestion methodology (ACM) using North Sea facilities and successfully applied it to over 60 facilities.

Figure 3 illustrates our basic approach. We are currently working on validating FLACS and other analytical tools' DDT onset prediction capabilities for scales and geometries relevant to GOM UDW structures. FLACS is a commercially available code that is currently used by over 100 companies. In order to achieve this goal, we have developed a large-scale test facility of 51,840 ft^3 (1,459 m^3) gross volume at a joint GexCon/SRI test site to study the potential of DDT for gases of varying reactivity (i.e., methane, propane, and ethylene) and will utilize the large-scale experimental data for FLACS and other analytical tools' validation. The tests will be conducted with various levels of congestion, confinement, and gas concentrations. The flame speed and overpressure measurements will be used for validation. Also, we will perform experiments that utilize mitigation measures (e.g., water deluge, solid inhibitor) to reduce the explosion consequences. The FLACS software will be updated and enhanced empirical models will be developed from the validation studies to extend their application to the large scale.

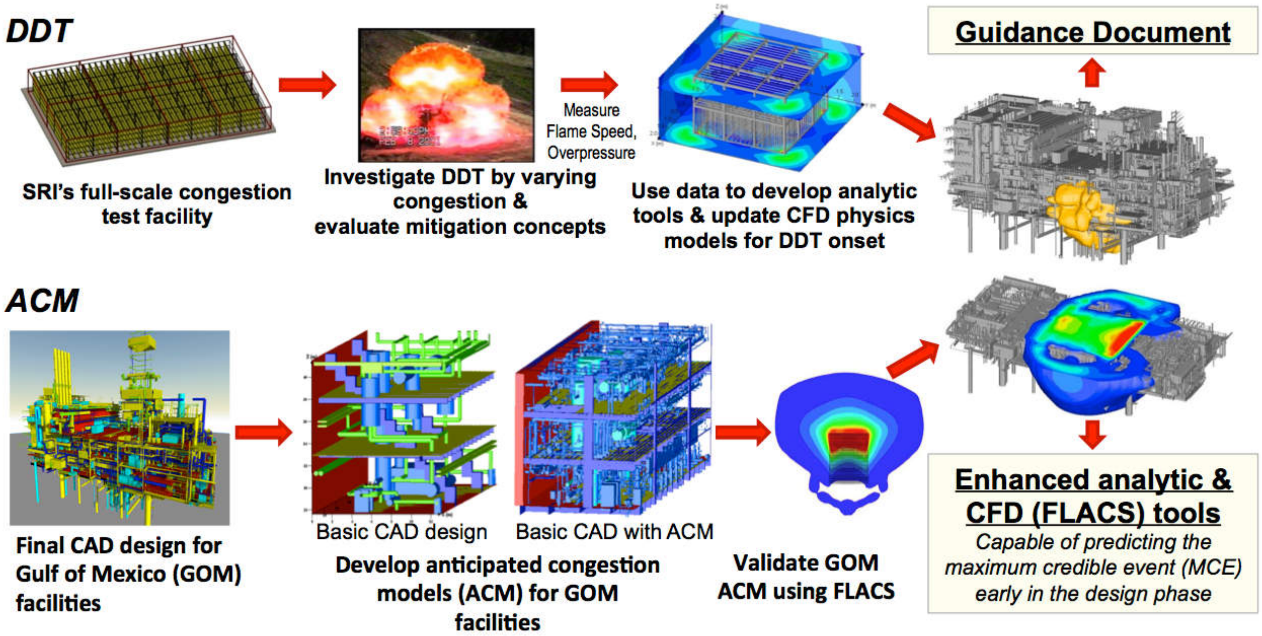


Figure 3: The GexCon/SRI approach to update and validate the FLACS CFD code for predicting DDT onset and developing ACM for GOM facilities.

To enable prediction of explosion hazards in the early design phases (concept or FEED phase), GexCon is working to further develop their ACM for GOM offshore drilling and production facilities. This methodology will define what levels of anticipated congestion are necessary to supplement CAD models in early design phase to ensure accurate assessment of explosion hazards. We will first provide numerical test results (explosion pressure and ventilation) for GOM topside structures that have detailed "as-built" CAD models. We will then gradually reduce the design detail of the "as-built" model and provide the explosion pressure and ventilation as a function of object density and design detail. Next, we will take CAD geometry models in early design stages (for the same topsides) and gradually implement anticipated congestion to evaluate explosion blast loads, then compare results with those obtained for detailed "as-built" design. We will adjust the ACM until the CAD models in early design stage have congestion levels sufficient to produce overpressures that match those from the final fully detailed models. The results of this project will provide oil and gas companies operating in the GOM the tools necessary to design "inherently safer" offshore facilities that can survive VCE incidents and prevent escalation, when the project is in the early design stages. As these tools will be available early on, designers will be able to make design changes and have detailed explosion overpressure information early in the design phase, which can minimize costs by avoiding pitfalls and changing designs in late phases.

Large Scale Testing

GexCon combined with SRI to develop a joint large-scale explosion area at SRI's 480 acre CHES site in California. A large-scale test pad was constructed in January 2015, which covered a test area of 33 ft by 196 ft (10 m x 60 m). An overview can be found in Figure 4. This test pad was designed for continued use after the proposed RPSEA test matrix. Several thermocouples are also embedded within the concrete for use in potential spill tests in the future.

Figure 4: SRI Test Pad.

As part of the testing plan, GexCon and SRI have developed a modular test assembly. This will allow for extensive flexibility in the testing, whereby congestion levels and congestion orientations can easily be modified within the rig. Several design iterations were evaluated to ensure the durability of the rig. The plan is to create an array of these modules with 2 modules across, 15 modules deep and 1 module high as shown in Figure 5.

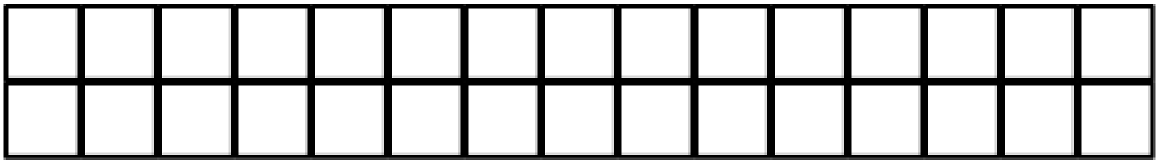


Figure 5: Rig array to be assembled.

FEA was used to evaluate the rig design and Figure 6 shows the stress analysis that was performed for a DDT event on the final module design. This figure shows the rig will very likely survive under the loads from a DDT occurring within the rig. The highest loads will be near the actual transition to detonation, which is red section of the rid in Figure 6.

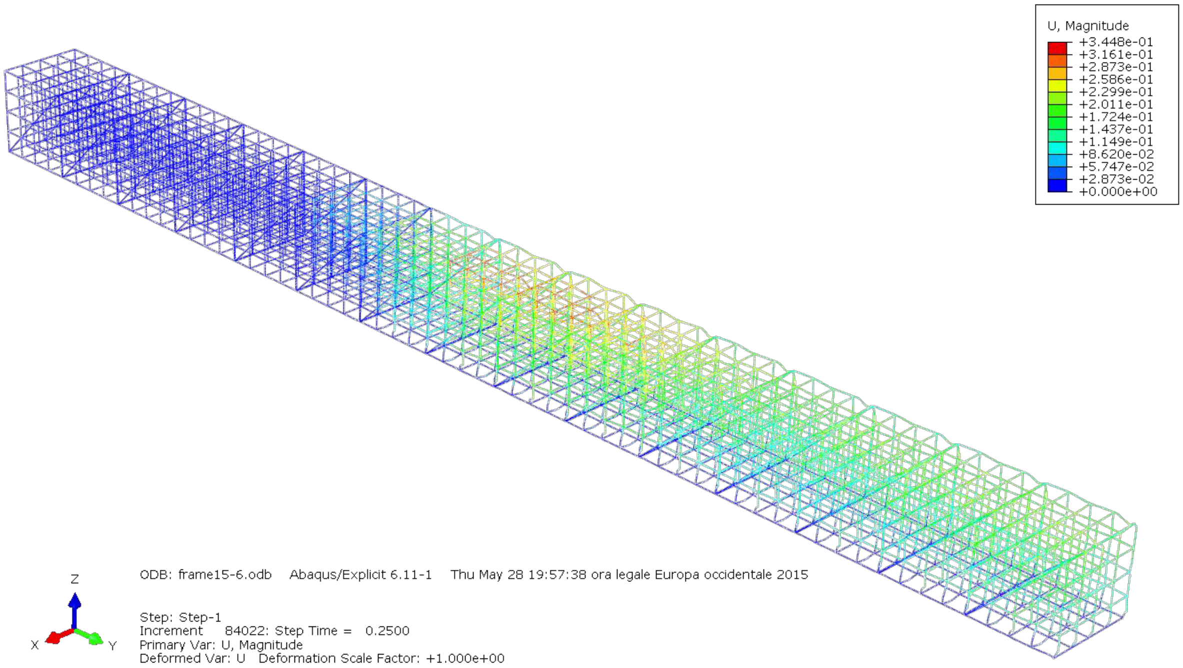


Figure 6: FEA analysis of the final rig design.

Six modules have been delivered to the test site at the time of this submission. To assist in understating the size of these modules and the final test volume, please refer to pictures (Figure 7 and Figure 8) of the first six modules delivered to the test site.

Figure 7: Modules being delivered to the test site.

Figure 8: First modules on the test site.

The proposed testing is to evaluate three fuels of varying reactivity under three levels of congestions. The expectation is that the highest reactivity fuel (ethylene) will transition to DDT in the lowest congestion level, the medium reactivity fuel will transition to DDT in the medium congestion, and to evaluate the likelihood of methane DDT in high congestion. The proposed test matrix is shown in Table 1. With the remaining time and budget, we plan to investigate active mitigation measures such as deluge or solid inhibitors.

Table 1: Proposed test matrix. Tests highlighted in green to be conducted first, yellow second and red last. Tests marked with an asterisk will be repeated if DDT is achieved.

		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	

In order to vary the level of congestion in the modules, hundreds of approximately 7-inch and 2-inch pipes were purchased and delivered to the test site (see Figure 9 and Figure 10).

Figure 9: Pipe at the test site to be used in the congestion array.

Figure 10: Pipe at the test site to be used in the congestion array.

In parallel to the design evaluation, a preliminary study was conducted on various congestion levels using FLACS CFD software. As stated earlier, the goal is to achieve DDT with stoichiometric concentrations of ethylene, propane and methane in their respective low, medium and high congestion levels. Over 200 CFD calculations have been executed for rig congestion optimization and included running sensitivities on grid cell size, time step (CFL numbers), and pipe sizes and pipes needed per row of congestion. As an example, the rig geometry itself was determined sufficient to achieve DDT with stoichiometric ethylene and was chosen to be the low level of congestion. The results for ethylene and propane are shown in Figure 11 and Figure 12 .

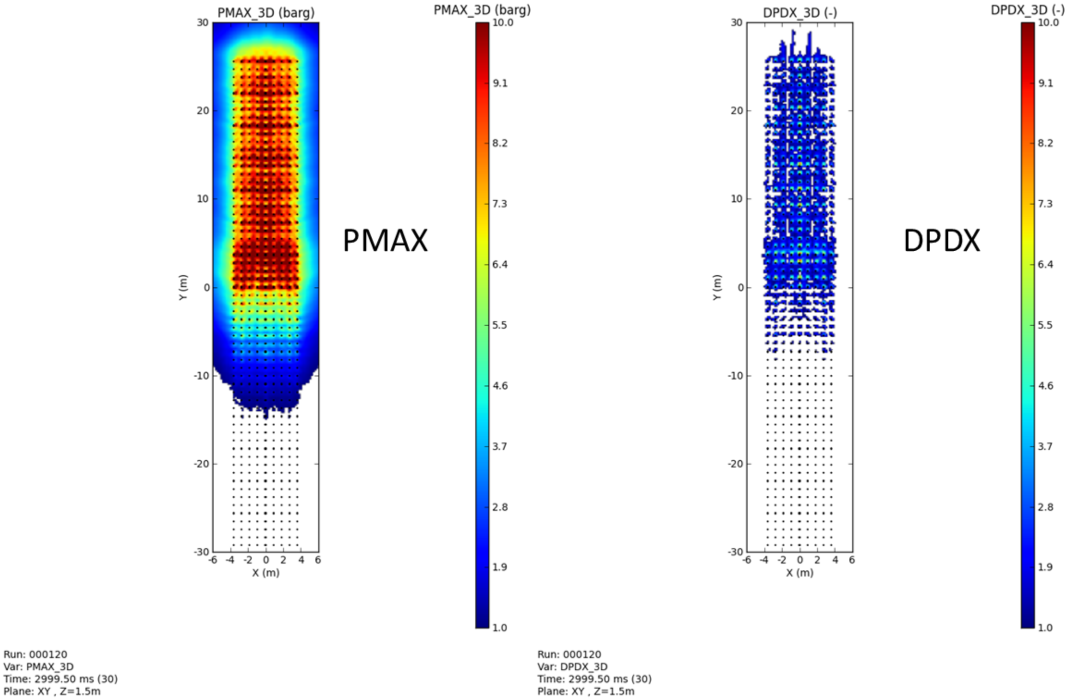


Figure 11: Maximum pressure (left) and DPDX (right) for FLACS simulation with stoichiometric ethylene and no pipes per row.

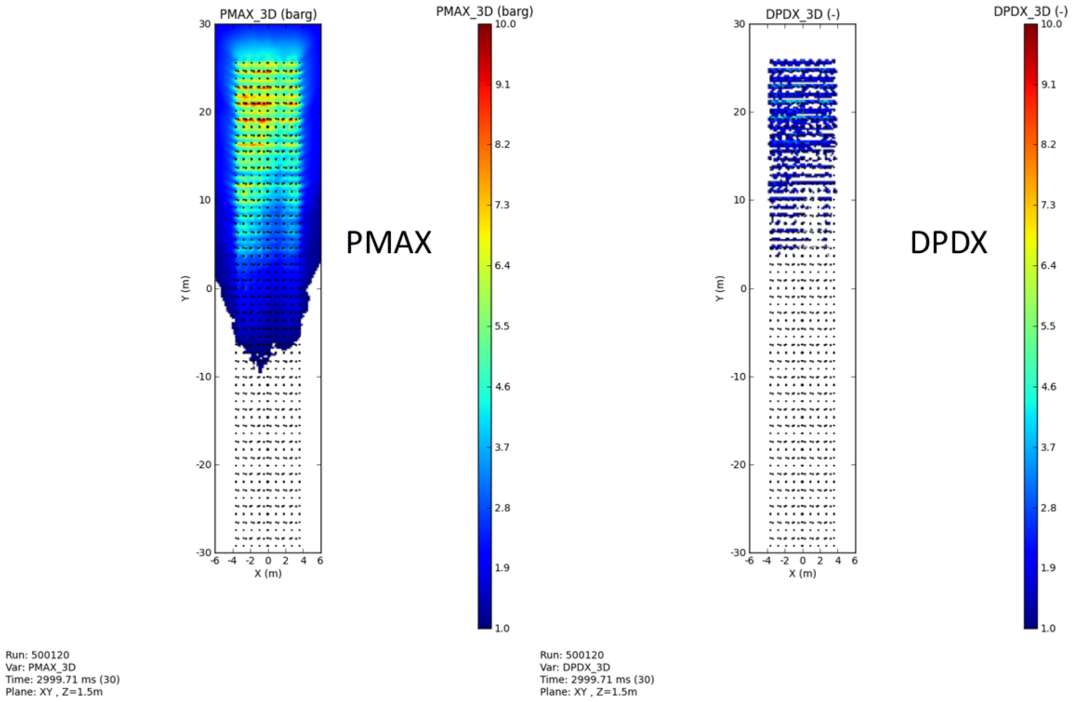


Figure 12: Maximum pressure (left) and DPDX (right) for FLACS simulation with stoichiometric propane and 7" pipes per row.

Figure 11 and Figure 12 show the maximum pressure (left) and the dimensionless DPDX parameter (right) that FLACS uses to predict the onset of DDT. For DPDX values less than one DDT is unlikely. DDT becomes possible with DPDX values of one through five. For DPDX values greater than five DDT become probable. Our target for predictions was DPDX values of 10.

At the time of this submission, no tests have been performed, however preliminary targets have testing taking place within the coming month.

Anticipated Congestion Methodology

The idea behind the anticipated congestion task was to bridge the gap between explosion overpressure predictions at early design phase with as-built platforms. From our experience, the resulting overpressure can differ by one to two orders of magnitude depending upon the congestion level present in the early phase designs. Figure 13 illustrates three different design phases, Concept, Feed and EPC. Each of these shows a resulting higher overpressure loads from CFD simulations performed with each geometry level of detail.

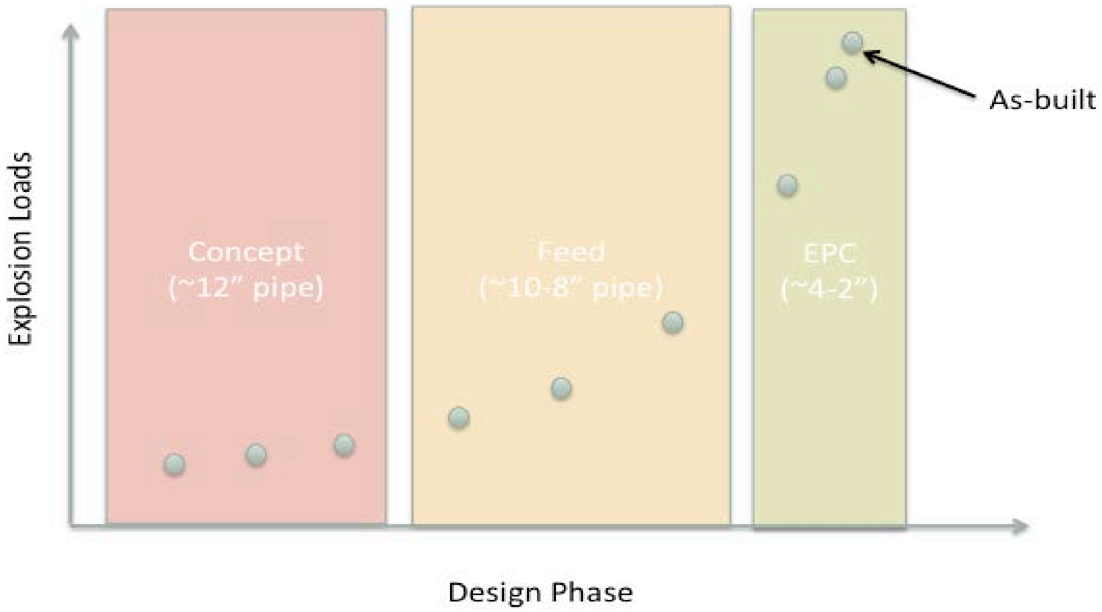


Figure 13: Overpressure versus design phase (model completeness).

In order to help bridge the gap between these early and late geometries, GexCon has proposed to investigate this in two styles. The "top-down" approach will focus on starting with as-built geometries and slowly remove pipes smaller than 2 inches, then 4 inches and onward to evaluate at which point predicted overpressures will begin to deviate significantly from those predicted using the as-built geometry. The "bottom-up" approach will start with early concept and FEED phase geometries and begin to add in anticipated congestion. The anticipated congestion will include both random pipe placement and more detailed pre-built skid placement meant to represent the congestion levels that would be present at an as-built completeness.

GexCon has begun to run congestion counts and evaluate overpressures on completed as-built geometries from our in-house library using the above outlined methodology. In addition, our cost-share partners Total, Shell and Chevron will also provide as-built models and well as earlier design phase for a variety of offshore facilities Overviews of some as-built geometries can be found below in Figure 14.

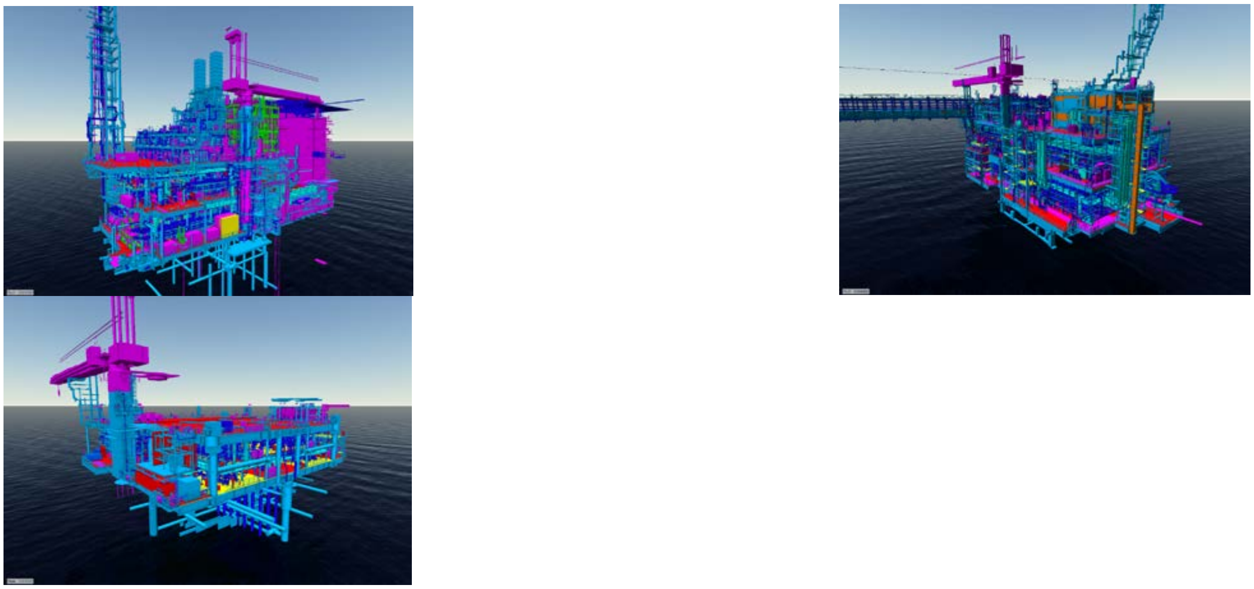
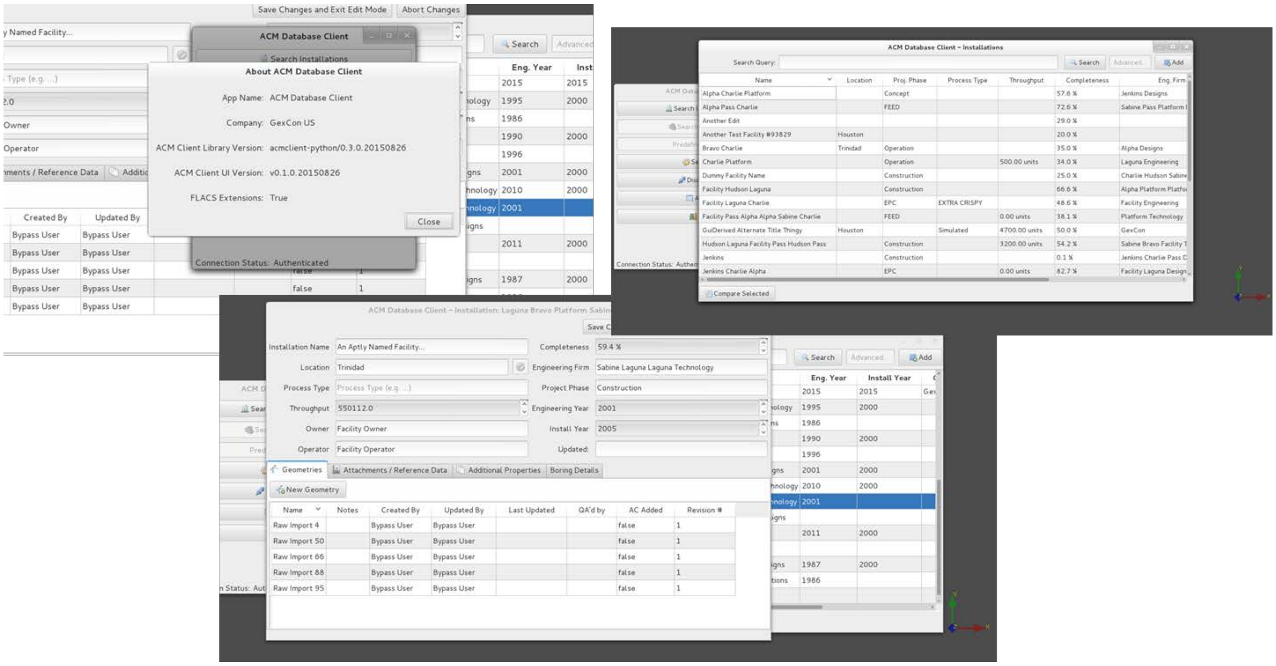


Figure 14: Examples of as-built geometries in GexCon's library.

These models are currently being documented and added to our ACM database (details to follow) as well as setup for the necessary ventilation and explosion simulations. Simulations have begun by removing various levels of congestion (e.g., below 2-inch, below 4-inch, etc.) and evaluating the explosion consequences.

In order to help assess final as-built congestion levels and compare those with information available in early design phase requires comparison with numerous as-built facilities. GexCon is undertaking efforts to document as many platforms as possible and populate an ACM database. Within this database will be details for each section of an offshore installation and will include various details such as designer, throughput, year built, owner/operator, process type, location etc. This database will be easily modified and amended as necessary, and also will include functionality to re-run congestion counts for future releases or developed congestion quantification schemes. Some early screenshots of the ACM database development can be found in Figure 15. This database will be available both as a plugin to the FLACS preprocessor CASD and as an independent database. This database is on target for an early completion at the end of this calendar year.



About ACM Database Client

App Name: ACM Database Client
Company: GexCon US
ACM Client Library Version: acmclient-python/0.3.0.20150826
ACM Client UI Version: v0.1.0.20150826
FLACS Extensions: True

Connection Status: Authenticated

ACM Database Client – Installations

Search Query:

Name	Location	Proj. Phase	Process Type	Throughput	Completeness	Eng. Firm
Alpha Charlie Platform		Concept			57.6 %	Jenkins Designs
Alpha Pass Charlie		FEED			72.6 %	Sabine Pass Platform
Another Edit					29.0 %	
Another Test Facility #93829	Houston				20.0 %	
Bravo Charlie	Trinidad	Operation			35.0 %	Alpha Designs
Charlie Platform		Operation		500.00 units	34.0 %	Laguna Engineering
Dummy Facility Name		Construction			25.0 %	Charlie Hudson Sabine
Facility Hudson Laguna		Construction			66.6 %	Alpha Platform Platfo
Facility Laguna Charlie		EPC	EXTRA CRISPY		48.6 %	Facility Engineering
Facility Pass Alpha Alpha Sabine Charlie		FEED		0.00 units	38.1 %	Platform Technology
GuiDerived Alternate Title Thingy	Houston		Simulated	4700.00 units	50.0 %	GexCon
Hudson Laguna Facility Pass Hudson Pass		Construction		3200.00 units	54.2 %	Sabine Bravo Facility T
Jenkins		Construction			0.1 %	Jenkins Charlie Pass C
Jenkins Charlie Alpha		EPC		0.00 units	82.7 %	Facility Laguna Design

ACM Database Client – Installation: Laguna Bravo Platform Sabin

Installation Name: An Aptly Named Facility...
Location: Trinidad
Process Type: Process Type (e.g. ...)
Throughput: 550112.0
Owner: Facility Owner
Operator: Facility Operator
Completeness: 59.4 %
Engineering Firm: Sabine Laguna Laguna Technology
Project Phase: Construction
Engineering Year: 2001
Install Year: 2005
Updated:

Name	Notes	Created By	Updated By	Last Updated	QA'd by	AC Added	Revision #
Raw Import 4		Bypass User	Bypass User			false	1
Raw Import 50		Bypass User	Bypass User			false	1
Raw Import 66		Bypass User	Bypass User			false	1
Raw Import 88		Bypass User	Bypass User			false	1
Raw Import 95		Bypass User	Bypass User			false	1

Eng. Year	Install Year
2015	2015
1995	2000
1986	
1990	2000
1996	
2001	2000
2010	2000
2001	
2011	2000
1987	2000
1986	

Figure 15: Preliminary database screenshot.

Conclusion

Preliminary work for large scale testing has been nearly completed with a test matrix set to start running in the coming weeks. Work has also started early on the anticipated congestion tasks with GexCon's in-house as-built library. This paper provides the latest update for GexCon's award of RPSEA Subcontract 12121-6403-01.