Behavior of Steel Structures in Accidental Explosion Events

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In conventional structural design, large deformations are often prevented to simplify calculations. However, only a small portion of a structures full capacity is utilized by doing so. Merely 21%(!) as shown by this study. Consequently, significant weight and project cost reductions can be made if large displacement theory is applied in the design process.

Steel structures in an offshore processing environment must be designed for an accidental explosion event. Regulatory documents provide a framework of general safety criteria, defining hazardous subsequent effects associated with an accidental explosion to consider in the design of a structure.

Pipe rack structures

This study focused solely on pipe rack structures located on an offshore topside processing facility. A pipe rack structure consists of mainly two structural components as shown in Figure 1; (1) a frame structure highlighted in yellow and (2) pipe lines supported by the frame structure (colored red and blue) containing hydrocarbons or other fluid content.

A broken pipe could act as a fuel resource, potentially intensifying fires caused by an initial explosion or causing new explosions due to the highly ignitable and explosive nature of the hydrocarbons. The goal of the design process is therefore to ensure that the frame structure will not deform in such way that a pipe line brakes if an explosion were to occur.

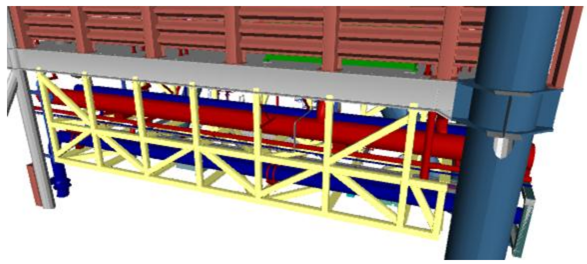

Figure 1 - Typical pipe rack configuration

Large vs. small displacement theory

In order to determine how much damage a pipe rack will suffer to an explosion, structural analysis must be performed using commercial computer software. Within such software, the engineer may build a model of the structure and apply different types of loading to it. Input, such as material data, is specified before the software can begin its calculations and analysis of the structure's behavior to the simulated explosion. When completed, the engineer can extract information which tells her/him how much the structure will deform and how much damage the explosion imposed on structural members.

The calculations will be different if large structural displacements are anticipated and the engineer must specify this when setting up the analysis in the computer software. In order to maintain a reliable analysis, the engineer must be knowledgeable on the theory that governs how structures behave when undergoing large deformations. This theory is more advanced than theory for small deformations, which is why many engineers cannot use it. When a structure is subjected to a large load such as an explosion, small deformation theory cannot be used to calculate the response accurately if displacements are large. The only solution is therefore to make the structure bigger and stronger so that deformations will remain small.

In this study, large displacement theory was used to analyze a pipe rack that had been designed by use of small displacement theory in a previous project. Consequently this original design was assumed to have a significant spare capacity, i.e. assumed to be able to resist a much larger explosion that what it had been designed for. The objective of the study was to determine how big of an explosion it could actually resist.

Simulation of an explosion

A gas explosion on an offshore topside structure will affect a pipe rack much like an ordinary wind gust. The explosion wind however is much stronger and very rapid. It is therefore defined as a pulse excitation when the explosion is simulated in analysis software. The explosion wind is best characterized by a symmetric triangular pulse shape as shown in Figure 2.

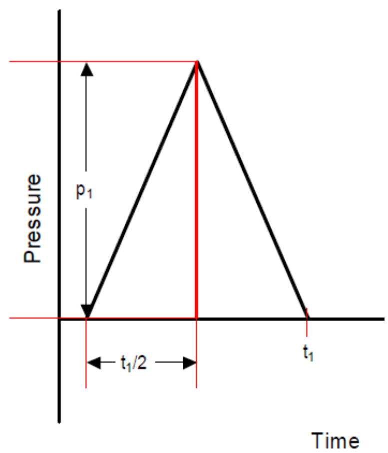

Figure 2 - Explosion wind defined as a triangular pulse

The triangular pulse in Figure 2 illustrate how the wind pressure from an explosion will increase from zero to its peak value (p_1), which occurs at a time equal to half of the total length (also called duration) of the wind gust. It will then decay and vanish at the end of the pulse duration, at time t_1.

The pulse governing the design of the pipe rack evaluated in this study had a peak pressure of 20 kilopascal and a duration of 50 milliseconds. In order to grasp the strength of this explosion, 20 kilopascal is approximately equal to the pressure that a 1 m^2 large table will feel if 20 people stand on top of it, weighing 100 kilogram each.

When small displacement theory was used to create the pipe rack design, the pulse characterized above defined the maximum load that the pipe rack could withstand before pipe lines were critically damaged.

Results

When calculations in this study were made more advanced by the use of large displacement theory, it was found that the wind pressure could be increased almost five times before the pipe lines got too damaged. So instead of a maximum resistance represented by a wind pressure equal to the weight of 20 people standing on the table, the true capacity of the pipe rack was in fact equal to a pressure generated by the weight of almost 100 people.

Results presented above show that structures design for explosions are usually made stronger and heavier than necessary. When large deformation theory is used to calculate the response, the size and weight of the design can be reduced. Reduced weight also implies reduced material costs. However, calculations using large displacement theory are more advanced and costly. At the end of the day, the question is wheatear saved material costs can make up for the cost induced by this more advanced analytical approach.