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Fire integrity of flanges

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The risk of fire in process plants containing flammable material requires precautions and protection of vulnerable components. To prevent escalation it is important that the process equipment retain its integrity during fire exposure. Studies have shown that flanges are among the weakest points in a process. Calculation of fire resistance of flanges is considered rather complicated, since it involves thermal conduction through fire insulation in complex geometries of metal and voids of air, stress of bolts, all depending on temperature history.

This paper presents results of a 4” ASME flange, from a project where experiments and calculations of a number of 4” and 10” flanges have been conducted, to explore the issue. The jet fire test series includes flanges with and without passive fire protection.

1 Background

Fire exposure of steel piping and flanges may results in rupture and release of content of the piping. In previous studies, it is shown that for many applications, the nuts and bolts of flanges represent a weak change when exposed to fire. Bolts on flanges are to large extend pre-stressed (above 50% of ultimate strength) and will therefore be sensitive to heating.

The principles of structure design of piping to avoid or resist fire exposure, is significant for offshore safety, especially to avoid escalation. In case of fire, thermal response to nuts and bolts is essential to keep integrity of piping. The purpose of this study was twofold; one was to establish and verify a scalable numerical temperature response model of ASME flanges and NORSOK compact flanges. The secondly, to include the effect of fire protection by use of “fire nuts” provided by Trelleborg.

Calculated results are compared with experimental results. Fire tests of flanges are previous carried out by SINTEF NBL and the results are reported by references Sæbø (2009). For scaling purpose, fire test results at different sizes are required. To provide such data, fire tests are prepared and instrumented to supply the optimal input of experimental data of 4” and 10” flanges. The fire test of 10” flanges are exposed by jet fire of approximately 0.5 kg/s providing heat exposure at more than 300 kW/m^2, reference Opstad (2009). The tests using flanges with diameter less than 4”, was

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exposed to a jet fire using 0.3 kg/s propane according to OTI 95 634. The average heat exposure for the first 10 minutes of testing is expected to be approximately 200 - 240 kW/m^2, distributed none isotropic around the pipe circumference.

2 Numerical tool, Brilliant

Brillant is a general CFD (Computation Fluid Dynamics) is objected oriented CFD code to handle complex geometry and to analysis multi physics depended problems simultaneously. A build in library for thermodynamic properties of fluids allow calculation of flashing and condensation of e.g. hydrocarbons.

Flanges are implemented by use of physical models of heat transfer by thermal conductivity and thermal radiation. To predict thermal response on flanges, the geometrical shape of specimens, thermal properties and boundary conditions have to be implemented, reference Opstad (2009).

In solids, heat conduction is the main heat transfer mechanism, while thermal radiation is as the main heat transfer from fires and the main heat carrier through voids in flanges. Voids are for the current example modelled between the discs, between bolts and discs.

For more complex studies with fluid content in the piping, fully flow and thermodynamic calculations can be conduced. For piping filled with air not pressurised, these processes are not considered to affect the results.

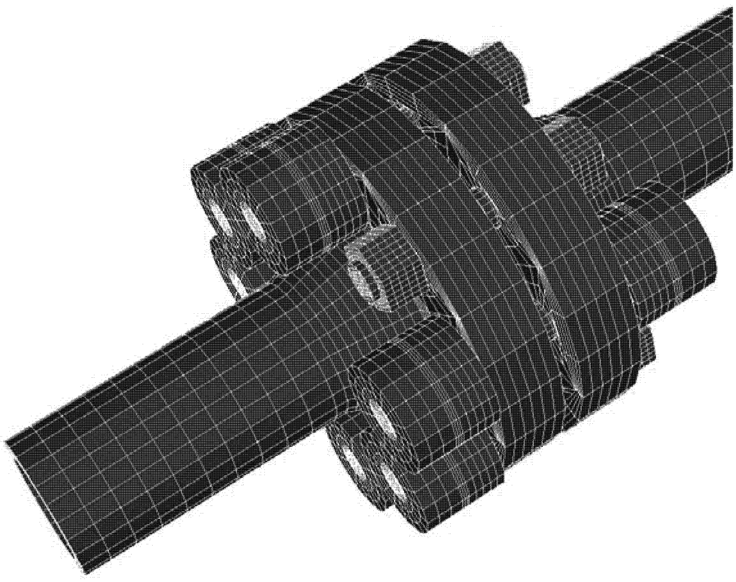

Figure 1 *Geometrical model of a 4" ASME flange (Weld neck). For validation purpose, protected and non protected nuts are uneven distributed around the discs of the flange*

3 Description of fire tests

A complete description of test method is provided by reference OTI 95 634 or in the SINTEF test report, reference Sæbø (2009). The fire source is an impulse driven jet fire of 0.3 kg/s exposing the test specimen(s) according to OTI 95 634 specifications.

Two 4” flanges were assembled in one fire test, see Figure below which show fire test set-up. The tubular samples are horizontally fixed in the front of a 1500x1500mm and 500mm deep steel box (front open). The rear side of the front box is insulated with 25 mm ceramic fibre mats.

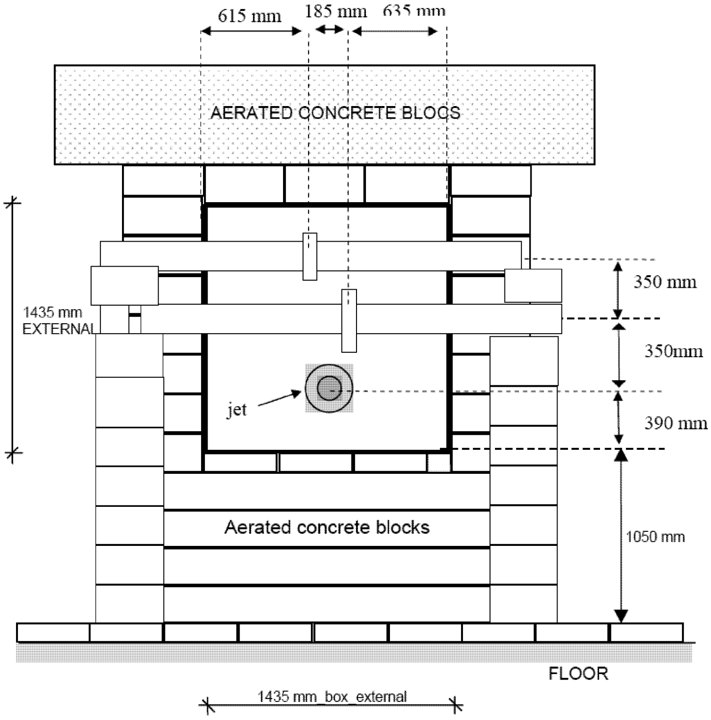

Figure 2 *Jet fire test setup. The heat point of the jet shown below the two tubulars. The jet flow is 0.3 kg/s propane and the construction is made of light weight concrete and a steel box (1.4 m x 1.4 m x 0.5 m) behind the test samples. The steel plate of the box serves a radiant panel when heated*

The heat exposure from the standard jet fire is to a large extend affected by the test object it self. Even though it is normal to provide time temperature curves representing the exposure in fire testing, it does not provide reasonable accuracy for jet fire tests. The exact heat flux level reached in a test can not be stated. Heat exposure in the order of 150 – 300 kW/m^2 is expected, where the highest peak values appearing on small surfaces only. The heat distribution on tubular are reported not to be isotropic around the pipe circumference reference Sæbø (2009). For these calculations, the distribution of heat exposure is estimated as shown in the Table 1 below.

Table 1 *The estimated average heat distribution during first 10 minutes of exposure from jet fire tests (OTI 95 634), simplified model. In the calculation, the exposure is activated from time zero and lasting as long as the corresponding fire test.*

Tubular heat exposure	Tubular dimension
	4 inch
Tubular sector unit	**kW/m^2**
Front, facing jet fire	200
Top, facing upwards	240
Below, facing ground	200
Back, facing hot furnace wall	220

4 Comparing calculation with experimental results

This article is showing some of the results from the 4" ASME flange, where nuts where unevenly fire protected for the purpose of validation of numerical calculations tools. In the calculation, thermal properties for Stainless steel at high temperature is taken from Scandpower Guideline, reference Scandpower (1997), and thermal properties of fire nuts are not fully available. Based on heat conduction at ambient temperature, the elevated temperature depended data are estimated. The emissivity for all surfaces is assumed to be 0.7. The content of piping is ambient air and the pipe is open in both ends. The bolts are pre-stressed to design value.

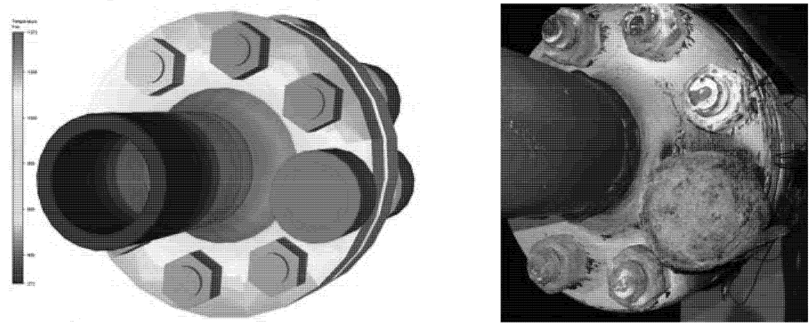

Figure 3 S*hows temperature distribution on 4" ASME flange, where the flange discs are holding temperatures of 750-850°C and non protected nuts are holding temperature of 900°C at the highest after 12 minutes exposure. The larger nuts, fire protected, are taking surface temperatures of 1100°C. The picture to right shows temperature affect on a fire tested stainless steel flange. The flange was not pressurized during exposure (empty).*

The calculated flange temperatures give good correlation on the disc surfaces, through disc into the inner diameter. Figure 4 below shows both the calculated and the measured inner temperatures of the flange. Figure 5 below is comparing calculated and measured thermal response in a non protect bolt facing the steel box at the rear side of jet fire exposure, see Figure 2. The calculated peek value is about 50°C above the measured value. The temperature history is not fully comparable, since that is an effect of simplified input of heat exposure shown in Table 1. Figure 6 shows temperature response in steel bolt when of the nuts are fire protected.

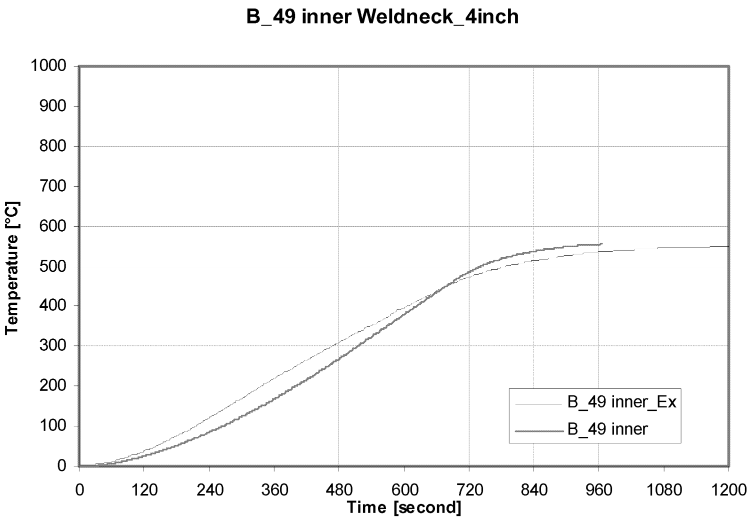

Figure 4 *The calculated and measured temperature of the inner surface of the 4" ASME flange disc*

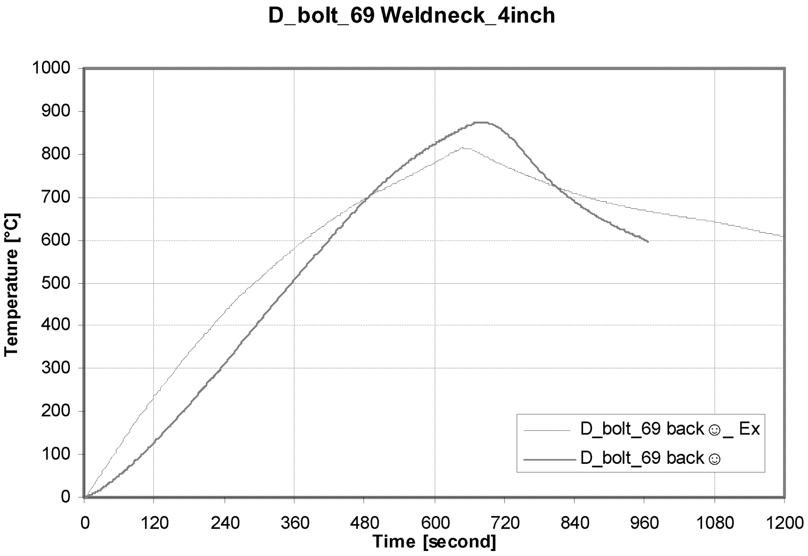

Figure 5 *The calculated and measured temperature of non fire protected bolts*

The temperature response of steel bolt with fire protected nut is shown in Figure 6. The peak temperature deviation is about 100°C. The results are strongly depended on the thermal properties of the fire protection. The data used is considered as approximate due to lack of more appropriate properties at elevated temperature.

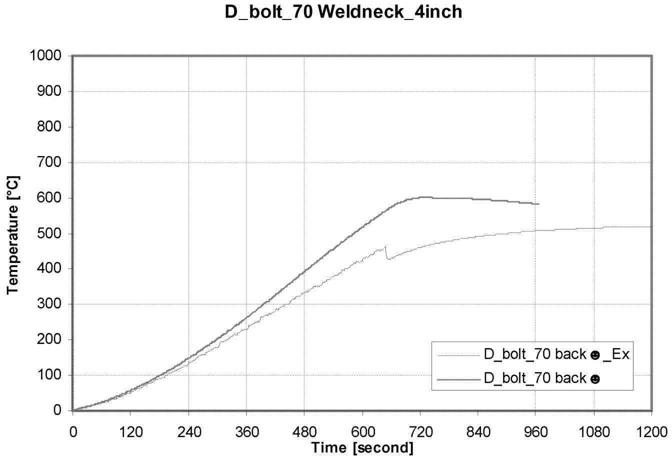

Figure 6 *The calculated and measured temperature of fire protected bolts ("fire nuts")*

5 Conclusion

Fire exposure of steel piping and flanges may results in rupture and release of content of piping. In previous studies, it is shown that for many applications, the bolts and nuts of flanges represent the weak change when exposed to fire. Bolt on flanges are to large extend pre-stressed (above 50% of ultimate strength) and will be sensitive to heating.

The principles of structure design of piping to avoid or resist fire exposure, is significant for offshore safety and especially to avoid escalation. In case of fire, thermal response to bolts and nuts are essential to keep integrity of piping. Calculation of fire resistance, are considered rather complicated, since in involves thermal conduction through fire insulation in complex geometries and stress of bolts, all depending on temperature history. Numerical calculation to define the integrity of flanges is possible, but still limited to access to proper thermal properties of insulation material at elevated temperature.

6 References

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