FMEA OF GASKETED AND NON-GASKETED BOLTED FLANGED PIPE JOINTS

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ABSTRACT

Limited work is available in the literature on the Failure Mode and Effects Analysis of bolted flanged pipe joints. From previous comparative reliability studies of both gasketed and non-gasketed bolted flanged pipe joints, generally it is found that both the joints are of high integrity and perform well in excellent service under appropriate installation and maintenance conditions. However, based on certain factors better functional safety of non-gasketed joints can be achieved. All studies have been performed based on operational information and reported observations. This study reported herein presents a detailed failure mode and effects analysis (FMEA) in the light of industrial surveys, analysis, experimental work and subsequent observations in addition to the previous studies. The aim of the study is to increase the reliability knowledge about the gasketed and non-gasketed flanged pipe joints and thereby to increase the basis for finding the optimal pipe connection based on surveys, observation and experimental studies performed.

Keywords: Gasketed, Non-gasketed bolted pipe joints, Failure Mode, Effects Analysis

INTRODUCTION

Over many years much effort has been expended to develop codes for piping and bolted flanged pipe joints to design a system of high structural integrity. In-spite of these efforts and the compliance of a successful design to such codes, the reliability of the system can still be adversely affected. This happens for a number of reasons. Poor construction practices, incorrect selection of components such as gasket, improper quality of bolts and surface treatment, incorrect tooling, wrong application, underestimated joint size due to incorrect loading consideration, incorrect use of code, lack of thought to plant use, or a change of use during the life of a plant may make a joint unsuitable. The list is not exhaustive and not all the possible causes of failure may become apparent even during commissioning. Failure of a pipe joint means the achievement of a leak rate below a certain maximum limit or the gross failure of the pipeline in which structural integrity is compromised or lost. The high reliability of a system can only be obtained if the right joint is selected for an application and factors that affect the reliability should be considered carefully. There are many different designs of flanged joints available. A flanged joint can perform well for many years in a particular application, but in a different application, the same joint may perform miserably for a variety of reasons. Experience from onshore and offshore gas installations has shown that the conventional gasketed pipe joint, has several weaknesses, which can cause problems in service [1,2,3-5]. So having examined the relative literature and after discussing problems faced by the oil and gas industry, it was decided to compare results from experimental testing, general observation and surveys of a standard gasketed (ANSI) joint with an equivalent alternative non-gasketed joint. The non-gasketed joint system arranged from VERAX Ltd. was chosen for study as it had exhibited best performance of a series of joint types previously analysed by the authors. These studies were based on detailed non-linear finite element analysis and examined other practical factors such as size, weight, amount of time required for installation and maintenance and overall cost of the joint [5-7]. In addition, two sub-types of non-gasketed joints (NG) i.e. with O-ring (NGIR) and without O-ring (NGER) were also evaluated in the present study. Risk probability factors based on experiments, general observations and surveys are developed and risk ranking results for risk assessment are summarized and discussed. It is noted that this work has limitations due to the lack of data for extreme operational incidents such as under fire exposure and trial field tests. It is considered that if such scenarios are anticipated then further studies are recommended in future so that proper failure modes and effects analysis (FMEA) could be performed to identify their reliability under such conditions.

ANALYSIS APPROACH

A qualitative failure mode and effects analysis (FMEA) was performed on same Det Norske Veritas (DNV) [8] pattern to compare the results for both the joints. In DNV study a probability factor of '0.75' was calculated and NG joint was concluded approximately 25% more safe than a conventional flange. In comparison to Webjorn's analysis [9] in which a few parameters were introduced and a probability factor of '0.31' compared to '0.75' showing the better functional safety of non-gasketed joints was concluded, this present study looks at non-gasketed joints with and without O-rings. Thompson's [10] quantitative analysis for comparative reliability by considering the basic design features i.e. Structural integrity and Plant maintainability criteria is also considered. In present study four frequency groups were defined and few parameters were also introduced, missing in the DNV study, such as sub-quality bolting and insufficient load capacity. Based on data for ANSI joint together with a qualitative analysis, it has become possible to give an estimate of the increased or decreased safety by using non-gasketed NG joint. By comparing the resulting probability factors for a conventional gasketed ANSI join, the level of functional safety for the non-gasketed NG joint was quantified on the basis whether it is 'better' or 'worse' in comparison to the ANSI joint. A qualitative comparison of the flanges was performed by dividing the features concerned into four categories related to;

1. Design and fabrication
2. Storage and handling
3. Installation
4. Normal operation

For evaluation purposes, each of these categories was subdivided into possible failure modes. Four frequency groups and three consequence groups were defined as follows:

Frequency grouping

Frequency	**Probability**
1	Expected to occur several times during the lifetime of the equipment
2	Likely to occur once during lifetime
3	The probability of occurrence during lifetime cannot be excluded

4 The probability of occurrence during life time can be excluded

Consequence grouping

Consequences **Seriousness**

1 Occurrence is likely to cause significant leakage
2 Occurrence is likely to cause minor leakage
3 Occurrence will probably not cause leakage, but reduce safety factor or require maintenance

Criticality factors

The criticality factor is defined as the frequency group multiplied with the consequence group, as shown in the following table, where **'1'** is very critical and **'12'** is not critical.

	Frequency			
Frequency Consequences	1	2	3	4
1	1	2	3	4
2	2	4	6	8
3	3	6	9	12

THEORY

DNV Technica has adopted a leak frequency function, which combines two components;

- A declining function of leak size which is independent of equipment size
- A rupture frequency which is defined as a leak equal to equipment size

General leak frequency function is defined as;

F(d) = *Not defined* *for d>do*
F(d) = $C\,d^m + F_{rup}$ *for do<d<D*
F(d) = *0* *for d>D*

Where;

F(d) = frequency of leaks exceeding size d (per year)
F_{rup} *= frequency of rupture (per year)*
D = diameter of equipment (mm)
D = equivalent diameter of leak
do = threshold diameter for reporting of leaks (mm)
C, m = constants

The baseline equation for the conventional ANSI flange joint given below is the standard DNV Technica leak frequency function for flanges offshore. It provides estimate of leak frequency as function of the size of the leak. They are more difficult to derive but are able to provide consistent leak frequencies for any leak size category.

$$F(d) = 2 \times 10^{-3}\, d^{-1.25} + 1.8 \times 10^{-5}$$

It is modified by a set of factors hereafter-denoted probability factors (P-factors). These factors are determined by introducing the distribution of causation. The weight factors are 0.16, 0.10, 0.30 and 0.44, their sum adding up-to 1. About 44% of all reported incidents occurred during normal operation, 22% during reinstatement, the weight factor for these set are 0.44 and 0.22 respectively. It is also believed that the flanges are quite sensitive to installation in order to work properly. Hence the weight factor is rounded up to 0.30. The design and fabrication related aspects are given more weight equal to 0.16 than storage and handling of 0.10. Modified equation is therefore given as;

$$F(d) = [2 \times 10^{-3}\, d^{-1.25} + 1.8 \times 10^{-5}]\, P_{design} \cdot P_{handle} \cdot P_{install} \cdot P_{normal}$$

$$P_{ANSI} = P_{design} \cdot P_{handle} \cdot P_{install} \cdot P_{normal} = 1.00$$

Consequently, if the product of probability factors (P-factors) equal to 1, then the functional safety of the joint in question is considered equal to an ANSI joint. Below 1 means ***'Better'*** and above 1 means ***'Worse'.***

Gasketed flange joint with four different gaskets and non-gasketed flange joint with and without O-ring were tested. Probability factors (FMEA matrix parameters) based on experimental results are summarized in Table-1 and based on general observations and surveys are summarized in Table-2. The calculation of P_{normal} for NG-joints is used as an example. By referring to the subtotal row of the normal operation block, the P_{normal} is calculated as;

$$P_{normal} = 1 + \left(\frac{\text{Sub total for ANSI} - \text{Sub total for NG}}{\text{Sub total for ANSI}} \right) \times 0.44$$

DEVELOPMENT OF PROBABILITY FACTORS

Probability factors developed based on experimental results, general observations and surveys given in Table-1 and Table-2, are discussed below in detail.

DESIGN AND FABRICATION

Seal ring/gasket material: For the NG joint with O-ring seal the possibility of material problems can not be excluded during the lifetime of the joint. However, the material failure of the seal ring will not cause leakage if there is no deformation on the flange surface. During the experimental programme, using the same O-ring for several repeat experiments, it was found top be worn out and its dimensions were reduced. However even though this dimensional change had occurred leakage was not observed [Figure 1a]. For a joint without a seal ring, there is no physical possibility of the occurrence of a seal ring failure. Comparing with the gasketed ANSI flange joint, which has had reported occasional gasket material problems, the NG joint is higher ranked when no gasket is present. During the experimental program [1], one of the gaskets after pre-loading was found to be damaged [Figure 1b], whereas the other two were found in good condition properly compressed. It is important to note that even though the flange joint was made in a controlled environment, the gasket still suffered damage.

Flange material: The likelihood for flange ring material failures and tolerances for the material comparisons are assumed equal for both joint types.

(a) (b) (c)

Figure 1: (a) New and used O-ring for NG Joint, (b) Damaged Gasket during Bolt Up, (c) Visual comparison

Bolting: High quality bolts with proper surface treatment, mechanical properties, origin of manufacturer and veracity of installation by means of calibration unit and tooling are of prime importance for NG joint. Whereas, for the ANSI joint no proper consideration is given generally to proper bolting, bolt pre-loading and it has been experienced that most of the bolts just wear out or fail during pre-loading and retightening [1,11].

Surface finish flatness and deviation in tolerance: For NG flanges in metal-to-metal contact to seal, the geometry and the surface finish are vital to the function. A small deformation on the flange surface can cause a significant leakage. Using an O-ring, a seal was achieved whereas without an O-ring, leakage was observed during the test. Deformation on all flange surfaces was measured after welding. Two NG flange assemblies were machined after welding even then leakage was observed due to incorrect tolerances and surface flatness. However, in the ANSI joint the gasket compensates for a small variation in surface flatness [12].

STORAGE AND HANDLING

Mechanical Impact: The term mechanical impact may include a drop on the floor. In this context, the weight of the flange joint becomes important. An ANSI joint is larger and very much heavier than a NG one and it is likely that ANSI joint may cause more damage. However, the NG joint can also be subjected to scratches, so the possibility is not excluded during the lifetime of the joint. However, during the experimental work, great care was taken in handling the flanges to save them from scratches or dropping [1-2,11,13,]. The visual dimensional comparison is obvious from Figure 1c.

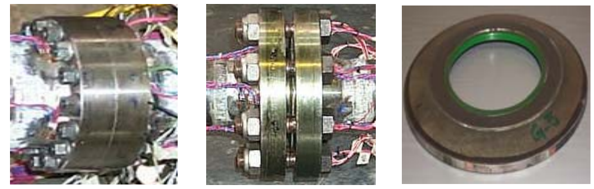
Surface corrosion during transport: If the surface protection from the vendor is in order then the corrosion is considered to be negligible for both the joints, Actual practice is such that no consideration of this is given for the ANSI joints when compared to NG joints which are assembled and specially packed for transportation. However, during the experimental work, no surface corrosion was observed.

INSTALLATION

Misalignment: The probability of angular misalignment between two pipes to be connected is high. ANSI flange joint is far more sensitive for misalignment. Commonly the ANSI flanges are mated after being welded to pipe. NG joints in principle are installed as units that eliminate this problem. When broken there ought to be no difficulty for reassembly. During the experimental study, flange joint assemblies have been manufactured from two different companies. One fabricator manufactured the joint assembly in separate form, the other manufactured it in clamped form, and the difference has been explained. For the former, a significant leakage was observed whereas for the later no leakage was observed from the joint without O-ring.

This shows that even a small misalignment due to deformation can affect the NG joints. However, NG joint is ranked better than the ANSI joint because the leakage was however found to be controlled by employing a seal ring [1,3-5]. Misalignment behavior of both the types of joints can be observed from Figure 2a,b. In addition effort to make a gasketed joint is comparatively large as compared to the effort required for non-gasketed flange joint.

Seal or gasket dislocation: An ANSI joint is considered more sensitive to seal i.e. gasket dislocation. For the NG joint with O-ring seal ring is positioned in the groove. For the NG, joint without O-ring no possibility exists for this reason. Due to the variability of the dimensions, the gasket was found to interrupt the bolts and therefore the gasket outer ring was machined to reduce its outside diameter. Although great care was taken to make it fit in the flanges, even then during the loading application the gasket seal ring was found to be bent to one side, which was observed after taking the gasket out of the joint - Figure 2c. This observation was also noted during industrial visits in a number of similar joints. This is attributed to some small misalignment in the mating pipe spools. From this, it can be concluded that it is not easy to properly align the gasket, which for example for the horizontal pipeline always moves vertically down due to gravity. Consequently, NG joint was ranked better than ANSI [3-5,13].



(a) (b) (c)

Figure 2: (a) NG Joint, (b) ANSI Joint, (c) Bent gasket during bolt up due to misalignment

Damage to gasket or flange: The gasket is always of softer material than the flange material itself in an ANSI joint. It has been found from experience that the gaskets often yield during joint make up due to higher or uneven pre-load. For the NG joint, there is no possibility of failure of the seal ring being in the O-groove [1]. Sketches of the NG (with and without O-ring groove) and ANSI flanges are shown in Figure 3. The gaskets used in the joint are of compressible material, which have a tendency to cold flow or take a permanent compressive set. Under these circumstances, their ability to follow the movement of the flange joint is reduced. The result can be leakage or poor performance. This has been observed in the experiments. The gasket was compressed to the required thickness at the recommended torque value. Gasket damage can be expected during the use of hammering and excessive flogging of the bolts. This also depends upon the joint location, where joint tightening may not be altogether straightforward. Similarly, damage is provided to the flange joint due to the flange rotation. This cannot be expected for the NG joint in metal-to-metal contact in which no flange rotation can be present.

(a) (b) (c)

Figure 3: (a) NG flange without O-ring groove, (b) NG Flange with O-ring groove, (c) Gasketed Flange

Non-uniform bolt pre-load: Non-uniform pre-load can be expected in the situation where the flexibility is present in the joint. In general this behavior is dominated in the ANSI joint due to the presence of the gasket, introducing bending moment to the flange connection and thereby causing a non-uniform gasket pressure. Whereas it cannot be expected for the NG joint due to more number of bolts pre-loaded to high level and due to no flexibility [11]. Even if a bolt is less pre-loaded it does not seems to make any visible difference to the sealing ability of the joint. This observation is plotted in Figure 4.

Lack of pre-load: In order to facilitate bolt pre-loading NG joints are delivered complete with proper tools e.g. long handle spanners for the bolts up-to 16 mm and hydraulic stud tensioners for heavier bolts to ensure the proper preloading. There is no proper consistent recommendation of pre-load application for the conventional joints across the industry. Gasket manufacturers recommend torque or tension figures to achieve the proper contact pressure, which cannot actually be completely guaranteed. During the experimental work, great care was taken and strains were recorded from each bolt, even then some of the bolts were found very much relaxed. This behavior is discussed in detail in [1,13-14].

Too high pre-load: With the conventional ANSI flange joints too high pre-load does induce warping of the flanges, concentrated bending in the bolts and non-uniform gasket pressure. In a NG joint, it is not the case. During the bolt behavior study the bolts were tightened above the proof load limit bolt but no yielding was observed [1,2,7]. It is also recommended for the NG joint to be made by the trained fitter to avoid any damage to the bolts.

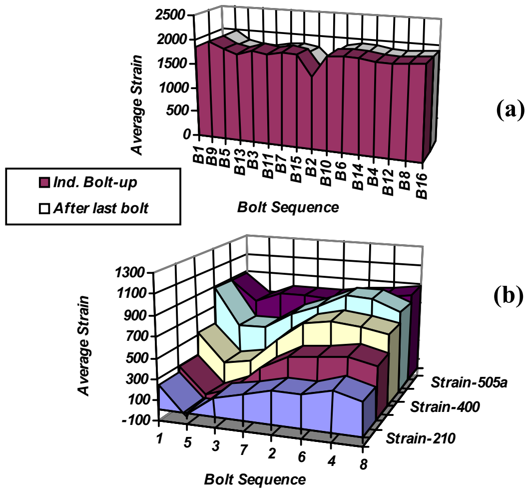


Figure 4: Average bolt strain variation during bolt up for (a) Non-gasketed NG flange, (b) ANSI-joint

NORMAL OPERATION

Fatigue: A dynamic mode, that is to say a variation of bolt load and stress with respect to time, operates in the ANSI joint. This in turn provides the potential for fatigue behavior to be present in the fillet between the neck and the flange itself, under the bolt head, and in the first thread outside of the nut [Figure 4]. In a NG joint a static mode is present and therefore results in no concentrated stresses, no bending of the bolt and hence no risk of fatigue [2,11].

Vibration: Vibrational loosening has an adverse effect on the joint leakage due to the loss of pre-load. This can be assumed where the flexibility is present in the joint. However, it has no ill effect on the NG joint due to higher pre-loading of the joint [1,2,7,15].

Wear/erosion: Wear implies damage in a dynamic situation [11]. Accordingly, it cannot possibly impair the functional safety of a NG joint.

Stress corrosion: In the conventional joint design, the strained shank of the bolts is exposed to the surrounding environment, which provides the possibility of failure due to stress corrosion. In the NG joints bolts are totally enclosed in the flanges and are isolated from the surrounding environment, which eliminates such a risk. Difference of both the joints is shown in Figure 2c.

Interface corrosion: Due to a zero gap between the flanges in a NG joint, there is no possibility of interface corrosion whereas on the other hand for the conventional joint this situation is present damaging the surfaces, gasket, and bolts and cause the leakage [Figure 2].

Pre-load loss: Lack of pre-load or relaxation is primarily attributed to the effect of gasket creep and plasticity. At the NG joint has only elastic stresses the mechanism completely different, and so a visible pre-load loss can not be expected from the NG joint. A detailed experimental study is carried out and results are plotted in Figure 4 [1,14].

Creep of gasket: With the ANSI joint, creep of the gasket can create a serious problem; with NG joint it is not since no gasket is present.

Frequency of maintenance: For the NG joint no maintenance is required whereas the ANSI joints need some maintenance due to the commonly reported leakage problems. From the experimental programme after pressure load test, the bolts were found to be relaxed and retightening was carried out. Even then some seepage was observed for combined loading application [1].

Load capacity: The various different international codes and standards for bolted flanged joints are principally based on sizing the joint to contain the main internal pressure loading. From experiments, the authors have determined that the load capacity is one of the most important considerations in order to establish the nature and magnitude of the design loads acting on the joint [13]. ANSI joints are designed on the base of internal pressure loading whereas NG joints are selected based on superimposing various load cases. During the experimental study, both the joints were tested for combined load applications to formulate a relationship for the working capability of both the joints and to observe their behavior.

RISK RANKING RESULTS

These are based on the various events which occurred (experimentally) and which may possibly occur (general observation), and the appropriate P-factors calculated are given in Table 3 below;

Table 3: Probability factors for both the gasketed and non-gasketed joints

Flange Joint	ANSI	NG (with O-ring)	NG (without O-ring)
P_{total} (Experiments)	1.00	0.162	0.116
P_{total} (General observation)	1.00	0.481	0.381

RESULTS DISCUSSION

P-factors calculated based on experimental results are lower than the general observations. The reason for this may be due to the number of assemblies tested but in actual practice the factor may be more where more samples of joints were used in the actual system. In addition, the experiments were performed under laboratory conditions and in a controlled environment with strain gauging of each bolt, flange and pipe section. Strains were recorded and it was ensured that to the bolt was prevented from yielding to obtain the exact average strain in the bolts during pre-loading. For the conventional ANSI joint these may be realistic conditions, but for the NG joint, the same bolts were tightened many times and they were found to be lubricated due to a previous leakage. Even then they have behaved well. Instead, a leakage from the joints without O-ring assemblies was noted except for one particular assembly (NGER) which indicates that the concept of metal-to-metal contact flange does indeed work. However, it fully depends on the quality of manufacturing and high joint pre-loading.

This gives the confidence that using an O-ring (seal ring) any small deformation produced during welding can be controlled to avoid leakage. However, given the results of the surface damage study [12], steps have been taken to revise the joint design and new welding procedures are being developed by the non-gasketed flange manufacturer VERAX Ltd. For conventional ANSI joints, the procedures are revised as mentioned in the recent document 'Guidelines for safe seal usage-Flanges and Gaskets' [16] published by European Fluid Sealing Associations. Keeping in view all the limitations mentioned in this study, the conventional gasketed ANSI joints provide a higher probability factor for failure compared to the non-gasketed NG joint.

CONCLUSIONS AND RECOMMENDATIONS

A failure mode and effect analysis has been performed for gasketed and non-gasketed bolted joint subject to ***normal conditions*** of design, manufacture, installation and operation. In these conditions, the non-gasketed joint performs better than the conventional ANSI gasketed joint. It is noted that the FMEA did not involve an evaluation of the properties in ***extreme operational conditions***, such as under fire exposure. The reason is that the base line data is based on a data collection process, which is gathered under normal operational conditions. Consequently, an FMEA with an evaluation of extreme operational failure modes would not be suitable for modifying the base line.

However, the properties of a pipe connection in extreme conditions are important. The fire resistance of the pipe joint should be equal to, or better than that of the pipe itself. In a complete evaluation of the functional safety of a modern pipe joint, it is considered of paramount importance, that also the effects of extreme operational incidents be accounted for.

During the present work, all the experiments were performed at the normal room temperature. However, it is recommended for future work to perform this on a trial field. Risk assessment studies can only be performed based on the available data but cannot be relied on the finite element studies, which very much depend upon the ideal boundary conditions.

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Table 1: FMEA Matrix Parameters in the light of experimental results

		ANSI			NG (with O-ring)			NG (without O-ring)		
		Freq	Cons	Crit	Freq	Cons	Crit	Freq	Cons	Crit
Design and fabrication	Seal ring material	1	2	2	3	3	9	4	3	12
	Flange material	3	3	9	3	3	9	3	3	9
	Quality of bolting	2	2	4	3	3	9	3	3	9
	Surface treatment	3	3	9	3	3	9	3	3	9
	Deviation in tolerance during -Machining	3	3	9	3	3	9	2	2	4
	-Fabrication/welding	2	3	6	2	3	6	2	1	2
	Sub total			**37**			**51**			**39**
	W-factor : 0.16	**P-factor: 1.00**			**P_{design} = 0.939**			**P_{design} = 0.991**		
Storage and handling	Mechanical Impact	2	3	6	3	3	9	3	3	9
	Transport/Surface corrosion	3	3	9	3	3	9	3	3	9
	Sub total			**15**			**18**			**18**
	W-factor : 0.10	**P-factor: 1.00**			**P_{handle} = 0.980**			**P_{handle} = 0.980**		
Installation	Misalignment	1	2	2	2	3	6	2	3	6
	Gasket dislocation	2	2	4	3	3	9	4	3	12
	Damage to gasket/flange	2	2	4	3	2	6	3	2	6
	Non-uniform pre-load	2	2	4	3	3	9	3	3	9
	Lack of pre-load	2	1	2	3	3	9	3	3	9
	Too high pre-load	-	--	--	3	3	9	3	3	9
	Sub total			**16**			**48**			**51**
	W-factor : 0.30	**P-factor: 1.00**			**$P_{install}$ = 0.400**			**$P_{install}$ = 0.344**		
Normal operation	Fatigue	1	1	1	3	3	9	3	3	9
	Vibration	--	--	--	3	2	6	3	2	6
	Stress corrosion	3	2	6	4	2	8	4	2	8
	Erosion/Wear	3	3	9	4	3	12	4	2	8
	Interface/galvanic corrosion	1	2	2	4	3	12	4	3	12
	Bolt pre-loading	2	2	4	2	3	6	2	3	6
	Creep of gasket	--	--	--	2	2	4	4	3	12
	Lack of maintenance	3	3	9	3	3	9	4	3	12
	Load capacity	1	2	2	3	3	9	3	3	9
	Sub total			**33**			**75**			**82**
	W-factor : 0.44	**P-factor: 1.00**			**P_{normal} = 0.440**			**P_{normal} = 0.347**		
Grand Total		**101**			**192**			**190**		
P_{total}		**1.00**			**0.162**			**0.116**		

Table 2: FMEA Matrix Parameters in the light of General observation and Surveys

		ANSI			NG (with O-ring)			NG (without O-ring)		
		Freq	Cons	Crit	Freq	Cons	Crit	Freq	Cons	Crit
Design and fabrication	Seal ring material	1	2	2	3	3	9	4	3	12
	Flange material	3	3	9	3	3	9	3	3	9
	Quality of bolting	2	2	4	3	3	9	3	3	9
	Surface treatment	3	3	9	3	3	9	3	3	9
	Deviation in tolerance during -Machining	3	3	9	3	3	9	2	2	4
	-Fabrication/welding	2	3	6	2	3	6	2	1	2
	Sub total			**37**			**51**			**39**
	W-factor : 0.16	**P-factor: 1.00**			**P_{design} = 0.939**			**P_{design} = 0.991**		
Storage and handling	Mechanical Impact	2	3	6	3	3	9	3	3	9
	Transport/Surface corrosion	3	3	9	3	3	9	3	3	9
	Sub total			**15**			**18**			**18**
	W-factor : 0.10	**P-factor: 1.00**			**P_{handle} = 0.980**			**P_{handle} = 0.980**		
Installation	Misalignment	1	2	2	2	3	6	2	3	6
	Gasket dislocation	2	2	4	3	3	9	4	3	12
	Damage to gasket/flange	2	2	4	3	2	6	3	2	6
	Non-uniform pre-load	2	2	4	3	3	9	3	3	9
	Lack of pre-load	2	1	2	3	3	9	3	3	9
	Too high pre-load	--	--	--	3	3	9	3	3	9
	Sub total			**16**			**48**			**51**
	W-factor : 0.30	**P-factor: 1.00**			**$P_{install}$ = 0.400**			**$P_{install}$ = 0.344**		
Normal operation	Fatigue	1	1	1	3	3	9	3	3	9
	Vibration	--	--	--	3	2	6	3	2	6
	Stress corrosion	3	2	6	4	2	8	4	2	8
	Erosion/Wear	3	3	9	4	3	12	4	2	8
	Interface/galvanic corrosion	1	2	2	4	3	12	4	3	12
	Bolt pre-loading	2	2	4	2	3	6	2	3	6
	Creep of gasket	--	--	--	2	2	4	4	3	12
	Lack of maintenance	3	3	9	3	3	9	4	3	12
	Load capacity	1	2	2	3	3	9	3	3	9
	Sub total			**33**			**75**			**82**
	W-factor : 0.44	**P-factor: 1.00**			**P_{normal} = 0.440**			**P_{normal} = 0.347**		
Grand Total		**101**			**192**			**190**		
P_{total}		**1.00**			**0.162**			**0.116**		