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A Discussion of Area Replacement Method in Opening Reinforcement Design and Use of Directive IB05-004 Rev.1

(I) Reinforcement of Openings

In the design of reinforcement of single openings (i.e., openings situated away from one another such that the stress patterns around the openings would likely not interfere with each other), there are many design methodologies available. In a number of pressure vessel design codes and standards (hereunder referred to as codes), the method that is most commonly found in the past and still very popular today is the “Area Replacement Method”. This is because the method is very simple in application and has proven to be relatively reliable and safe in practice, particularly with the commonly used design safety factors (sometimes known as design factors) of 3.0:1 on tensile strength or higher in the codes.

For this method, essentially, material in the vessel shell (i.e., the wall of any part of a vessel, including head, cylinder and others) removed by the opening in a view sectioned along an axis of symmetry of the opening, is to be replaced/compensated with material at a certain proportional ratio (typically the ratio, which is known as the *compensation factor*, is 1.0) of the removed area (and hence the name “Area Replacement”).

(II) Basis of Area Replacement Method

The logic and simplicity of this approach may be illustrated through the introduction of an opening in a flat plate. Assuming a flat plate which has a cross sectional area “**A**” is under loading “**F**” at either end of the plate as shown in Fig. 1.

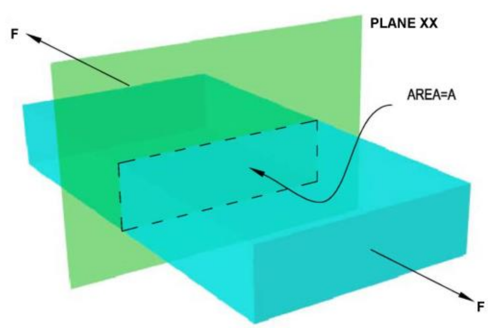

FIGURE 1

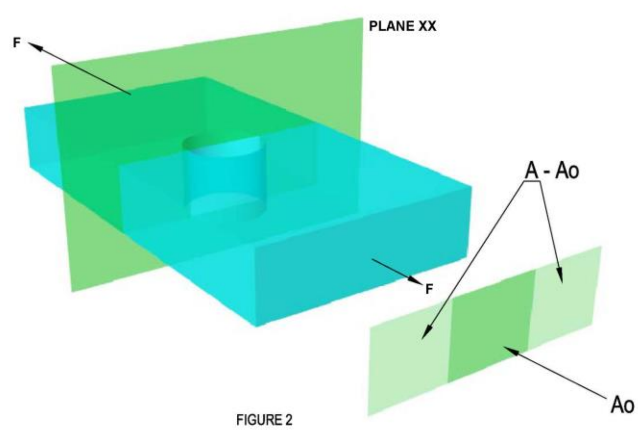

FIGURE 2

{ABSA: D0076624.DOC .2 }

The membrane stress in the plate across a section of the plate perpendicular to the loading (section X-X in Fig. 1) would be:

$$\sigma_{x\text{-}x} = \frac{F}{A}$$

However, when we introduce an opening, the cross sectional area of the plate **A** on a plane cutting the centre of the opening perpendicular to the axis of the loading will now be reduced by A_o (the area of the opening in the sectioned plane along X-X as shown in Fig. 2). With the introduction of the opening, without considering stress concentration at the edge of the opening or stress gradient along the plate cross section and other factors, the membrane stress will be increased to:

$$\sigma_{x\text{-}x} = \frac{F}{A - A_o}$$

Again, discounting other factors, if one were to try to maintain the same original membrane stress level previous to the introduction of the opening, one would have to re-introduce the same area A_o as added reinforcement material in the plate in order to cancel out the effect of the material taken out by the opening:

$$\sigma_{x\text{-}x} = \frac{F}{A - A_o + A_o} = \frac{F}{A}$$

And, in this case, we have just used the “Area Replacement Method” with a compensation factor of 1.0.

In this simple illustration, only the average membrane stress is considered with no attention being given to minimizing stress concentration in the vicinity of the opening and other effects relative to the interruption of the plate as a result of the introduction of the opening. Also, we are looking at a plate that is loaded in a uni-axial fashion with no bending and other loadings.

With that relatively simple illustration, it may be now concluded that a compensation factor of 1.0 is applicable for an opening in a flat plate under uni-axial loading condition. While this compensation factor of 1.0 is typically used in codes for simplicity of application, it can actually be easily confirmed with simple stress analysis that even for an opening in a plate under a bi-axial stress field, the factor of 1.0 would not result in the lowest stress level. But, as stated earlier, for simplicity and with a reasonable design factor of 3.0:1 on tensile strength or higher, Area Replacement Method has proven to be relatively reliable and safe in practice.

(III) Opening in a pressure vessel versus opening in a plate

Obviously, an opening in a pressure vessel is quite different from an opening in a flat plate under uniaxial loading. In a pressure vessel, with the introduction of an opening, not only one will be dealing with curvatures of the vessel shell in a bi-axial stress field (assuming a situation of a thin wall vessel only; i.e., longitudinal/meriodional and circumferential stresses), there will be edge loadings (both shear and bending) around the opening as well. Accordingly, typically, there are restrictions and special provisions (including diameter size, shape and location limitations) in the codes for the use of the Area Replacement Method. Bearing in mind that the Area Replacement Method is a simple but an imprecise analytical procedure, when the method is used, it is important to comply with all the restrictions and special provisions in order to achieve the desire level of safety provided by the codes.

(IV) Provision of reinforcement area and "integrally reinforced" opening

In providing area replacement in the "Area Replacement Method", the best approach would be to provide the replacement area physically near the opening. Thus in all codes, there are horizontal and vertical limits along the intersection of the centre of the opening and the vessel shell within which material may be considered as contributing to the replacement area. More importantly, consideration should also be given to whether the provided replacement material is integral part of the vessel shell or the opening nozzle neck. Material so provided (i.e., "*reinforcement provided in the form of extended or thickened necks, thickened shell plates, forging type inserts or weld buildup* which is an integral part of the shell or nozzle wall and where required, is attached by full penetration welds") will allow the nozzle be considered as being integrally reinforced (see ASME Section VIII Division 1 (see UW-16(c)(1)).

(V) Use of "Repad" and Pressure Retaining Material

Quite often, in addition to material available from the shell and the nozzle neck, more material is needed as replacement area. In some cases, the additional material is added on the shell as a pad around the opening and this is commonly known as a "reinforcement pad" or simply, a "repad" in opening reinforcement design. It should be noted that openings with repads can not be considered as integrally reinforced. This is partly because one cannot accurately ascertain how loading may be transmitted between the vessel shell and the nozzle through the repad.

Irrespective of how replacement material in Area Replacement Method is supplied, as seen in the above illustration, all replacement materials used in the Area Replacement Method must be considered as pressure retaining material and must be given due considerations in fabrication and inspection. And in the case of a repad, as seen in the illustration on the Area Replacement Method earlier, one would have to assume that it is really little different from that part of the shell taken out by the opening.

(VI) Use of Split repad and Directive IB05-004 Rev.1

When a repad is used, at times, for reasons of practicality but also, very frequently merely for convenience, the repad is split and then welded back together. There is no provision in the codes, including ASME Section VIII Division 1, to allow or disallow the use of a split repad. This subject matter is addressed in a recent Directive (see http://www.absa.ca/IBIndex/IB05-004R1.pdf).

In view of the fact that the use of split repad is not addressed by the codes, the Directive requires that ASME Section VIII Division 1, Paragraph U-2(g) be satisfied in that "*This Division of Section VIII does not contain rules to cover all details of design and construction. Where complete details are not given, it is intended that the Manufacturer, subject to the acceptance of the Inspector, shall provide details of design and construction which will be as safe as those provided by the rules of this Division*".

The intent of the Directive is to clarify that proper justification and design and construction details are required when a split repad is used so that the designer/manufacturer will have to provide proof that the use of the split repad will provide the same level of safety as if using an ordinary single piece repad. In the Directive, it is suggested NDE (radiography and possibly UT) may possibly satisfy U-2(g) and that suggestion should not distract readers from the intent of the Directive. Also, the use of NDE may not necessarily be acceptable "good engineering practice".

(VII) Caution to users of codes and standards

It is impossible for any code to provide all the details of different manners of pressure vessel construction. When no code rules are available, a designer must consider the proper design and construction methodology to achieve the same level of safety consistent with the other parts of the code where rules are provided. The use of split repads is only one example where details are not addressed in the codes.

When using any codes, readers are cautioned that codes can not replace good engineering judgements. Codes typically provide for minimum requirements which must be complied with, particularly, when such codes and standards are adopted as part of the regulations and thus, become part of the law of the land. All codes and standards note the importance of and the need for good engineering judgement and caution the users to exercise due diligence to ensure safety.

In the "Foreword" of the ASME Boiler and Pressure Vessel Code, it is stated that *"The Code does not address all aspects of these (sic construction) activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase engineering judgment refers to technical judgments made by knowledgeable designers experienced in the application of the Code."* . The Preface of the CSA B51-03 Boiler, Pressure Vessel, and Pressure Piping Code notes that "*Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose*".

Thus it must be concluded that codes do not preclude good engineering practices nor take away the responsibilities and liabilities of any users of the codes when good engineering judgments are not exercised.

(VIII) Conclusion

It is hoped that the foregoing discussion provides for a better understanding of the Area Replacement Method as used in opening reinforcement design and the basis of the Directive IB05-004 Rev.1 as well as an appreciation of the need for engineering judgment when using codes in the field of pressure technology when specific code rules and details are not provided.

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