

Strain Based Design—What the Contribution of a Pipe Manufacturer Can Be

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ABSTRACT

Exploration of new energy resources located in areas of complex ground and ambient climate imposes strict requirements on pipeline material and design. One of the major research issues in such areas is differential ground movement, which, possibly, is associated with large longitudinal straining in addition to plastic circumferential elongation. Hence, common design principles need thorough re-consideration, notably with respect to strain hardening properties of both base metal and girth welds. This paper summarizes results of a research, which was conducted within Europipe GmbH and supported by Salzgitter Mannesmann Forschung GmbH. Central to the discussion is the numerical representation of strain hardening behavior of pipeline steels, which mainly was focused on base metal. In particular, the discussion comprises stress-strain behavior in transverse as well as in longitudinal direction, the effect of material ageing and the significance of uniform elongation.

KEY WORDS: Strain hardening; design; uniform elongation; power law; true stress-true strain; engineering stress-engineering strain, UOE line pipe.

INTRODUCTION

With the sustained rise in both oil and gas price to record levels, hydrocarbon reserves that were considered too expensive to justify production only a few years ago are now being considered as attractive. Fortunately, advances in technologies for exploration and production do allow uneconomic reserves to be accessed (Martin, 2006). These “new” reserves tend to be in regions where difficult ground prevails. That is to say, more and more pipelines will be prone to large differential ground movements. Differential ground movements may have many reasons such as soil subsidence, frost heave, thaw settlement and landslides, to name a few. A phenomenon, which is common to such load scenarios, is that they may evoke large longitudinal strains in addition to plastic circumferential elongation. This is very much different to the case of bare pressure containment where, mainly, circumferential and radial components of strain tensor undergo plastic deformation. Since longitudinal strains may be tensile or compressive complex multi-axial stress states accrue with plastic deformation

developing in more than two co-ordinate directions, which, within a cross section, are not uniform any more. This imposes strict requirements on pipeline material and design. It appears that at least two parties can actively contribute to safe and reliable energy transportation solutions. While pipeline operators are responsible to deliver appropriate designs across well-balanced and rational principles pipe manufacturers are requested to supply advanced material solutions prone to fulfill what has been assumed during the design process. The possible contribution of pipe manufacturers in this context is one subject of the present paper.

In order to ensure pipeline safety, integrity and environmental impact an alternative design methodology, Strain Based Design, may serve as the key to such difficult pipeline applications (Mohr, 2006, Zhou et al. 2006). This is because loading in the sense of Strain Based Design tends to apply a given displacement rather than force to the pipeline. Most often, such displacements impose a radius of curvature to the pipeline, a result of which is a bending moment, see Fig. 1.

Meanwhile Strain Based Design is addressed in a number of design codes, e. g. CSZ Z662-03 (CSZ Z662-03 2003). Still, these do not give sufficient guidance as regards pipeline structural analysis. In principle, the methodology of Strain Based Design is developed in connection with the philosophy of Limit State Design, where it stands for a specific subset of limit states where displacement controlled loads dominate the mechanical pipeline response. In Limit State Design the design value of load action S_d is compared to the design value of the resistance side (material) R_d :

$$S_d \leq R_d \quad (1)$$

Therein, S_d is the sum of all individual load contributions multiplied by partial (safety) factors $\gamma_{S,i} \geq 1.0$:

$$S_d = \sum \gamma_{S,i} s_i, \quad (2)$$

with s_i being individual load contributions. The design value of the resistance is defined as the quotient of nominal (or “characteristic”) resistance R and the partial (safety) factor $\gamma_R \geq 1.0$:

$$R_d = \frac{R}{\gamma_R}. \quad (3)$$