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The Influence of Loading System Stiffness on Empirical Correlations for Determination of Tensile Characteristics from the Results of SP Tests

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Additional information is available at the end of the chapter

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Abstract

The present chapter describes the influence of the loading system stiffness on empirical correlations for determination of yield and tensile strengths at laboratory temperature from the results of small punch (SP) tests. The results obtained proved that measuring of test specimen deflection during SP test eliminates the significant effect of the loading system stiffness on the above-mentioned correlations.

Keywords: small punch test, load-displacement curve, empirical correlation, yield strength, tensile strength, specimen deflection

1. Introduction

The need for evaluating the actual mechanical properties of structural components by direct testing method has led to the development of innovative techniques based on miniaturized specimens. Among these, a technique called the small punch (SP) test has emerged as a promising candidate (Hurst and Matocha, 2010, Lucon, 2001, Lucas, 1990). It is a mechanical testing method used presently to obtain tensile, fracture, and creep data from very small quantities of experimental material. In 2007 CWA 15627 “Small Punch Test Method for Metallic Materials” (CWA 15627:2007 D/E/F, 2007) was issued by CEN (European Committee for Standardization).

The objective of the SP test is to produce a load-displacement (punch displacement, crosshead displacement, specimen deflection) record (see **Figure 1**), which contains information about the elastic-plastic deformation and strength properties of the material.

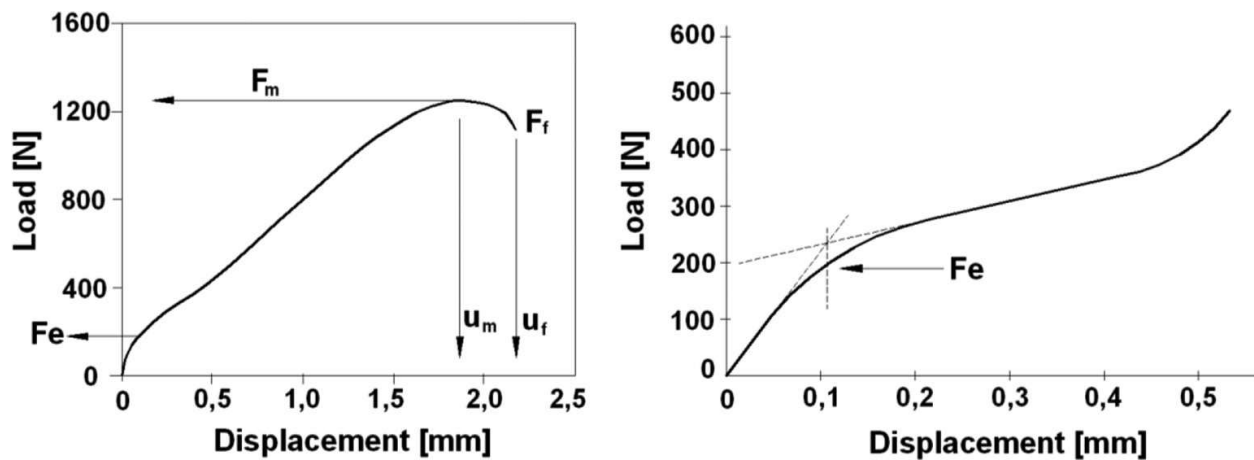


Figure 1. Load-displacement curve recorded during a time-independent small punch (SP) test.

The following parameters are determined from the load-displacement curve during the time-independent SP tests (CWA 15627:2007 D/E/F, 2007):

F_m [N]: maximum load recorded during SP test.

F_e [N]: load characterizing the transition from linearity to the stage associated with the spread of a yield zone through the specimen thickness. It is determined according to the Code by the two tangents method (see **Figure 1**).

u_m [mm]: displacement corresponding to the maximum load F_m .

u_f [mm]: displacement corresponding to 20% load drop.

E^{SP} [J]: SP fracture energy obtained from the area under the load-displacement curve up to the u_f .

The load-displacement curves obtained can be utilized to derive empirical correlations between SP and standardized test results (Mao and Takahashi, 1987, Hurst and Matocha, 2012, Rodriguez et al., 2012) or they can be analyzed in terms of elastic-plastic finite element methods (Nakata et al., 2010, Hůlka et al., 2012, Prakash and Ramesh, 2012, Madia et al., 2013).

Most of the empirical correlations for the determination of the yield strength from the results of penetration tests found in the literature are expressed as the dependence of the yield strength on the parameter F_e/h_0^2 , where h_0 is the initial thickness of the disc, because it was proved that this parameter eliminates the effect of any differences in disc specimen thicknesses on load F_e (Dymáček and Ječmínka, 2014, Hurst and Matocha, 2012). Tensile strength is correlated either with the parameter F_m/h_0^2 or the parameter $F_e/(u_m \cdot h_0)$, because it was proved that this parameter eliminates the effect of any differences in disc specimen thicknesses on load F_m and u_m (Hurst and Matocha, 2012). There is, however, an important factor affecting the shape of the load-displacement record. This is a procedure used for the displacement monitoring. Only few authors have paid attention to the different possibilities for the displacement monitoring, i.e.,

punch displacement, bottom central point displacement (deflection), testing machine crosshead displacement, and loading system stiffness (Moreno et al., 2016, Matocha et al., 2014).

In the present chapter, the influence of the displacement monitoring method on empirical correlations for determination of yield and tensile strength for P92 steel was followed up. Both testing machine crosshead displacement and bottom central point displacement (deflection) were monitored during SP tests at laboratory temperature. It was proved that the monitoring of deflection eliminates the effect of loading system stiffness on the above-mentioned correlations.

2. Testing material

A steam pipe $\varnothing 219.1 \times 22.2$ mm made of P92 steel in as-received state was used as the testing material. Controlled chemical composition of the testing materials is shown in **Table 1**. The testing material was heat-treated to four significantly different strength levels (see **Table 2**). Tensile tests were carried out at room temperature on MTS 100 kN servohydraulic testing machine using round testing bars of 8 mm diameter.

C	S	Mn	Si	P	Cu	Ni	Cr
0.12	0.009	0.53	0.24	0.012	0.050	0.13	8.56
Mo	V	Ti	Nb	W	Co	N	Al _{tot}
0.43	0.19	<0.005	0.062	1.63	0.007	0.045	0.009

Table 1. Controlled chemical composition of testing material [wt.%].

State	YS [MPa]	UTS [MPa]	A [%]	Z [%]
As received	679	808	18.0	61
HT1: tempering 800°C/2 hours/air	502	675	26.8	67
HT2: tempering 760°C/2 hours/air	541	707	24.4	65
HT3: tempering 750°C/2 hours/air	574	726	21.4	66
HT4: tempering 740°C/2 hours/air	584	733	21.6	63

Table 2. Tensile properties after selected heat treatments.

SP tests at laboratory temperature were carried out on the servomechanical testing machine LabTest 5.10ST under control at crosshead speed of 1.5 mm/min. Both the crosshead displacement and the specimen deflection were measured during the SP test using testing jig for monitoring test specimen deflection (bottom central point displacement) (see **Figure 2**).

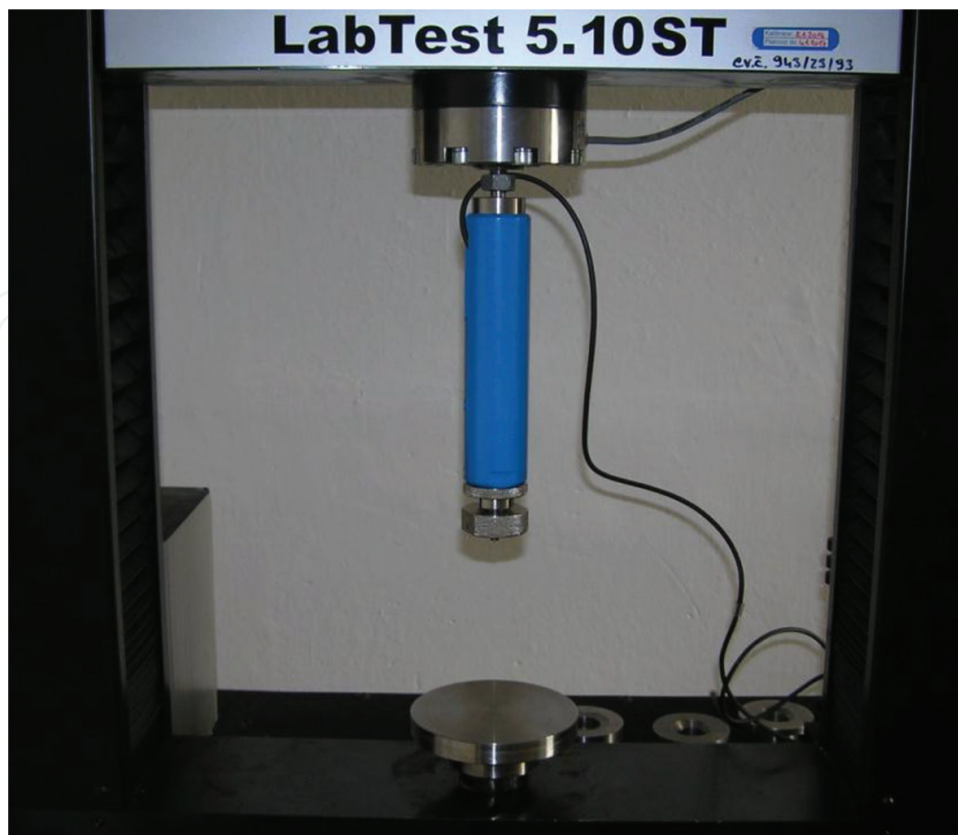


Figure 2. Testing facilities with the jig for monitoring test specimen deflection.

3. Results and discussion

Figure 3 shows the stiffness of the loading system used for SP tests at laboratory temperature.

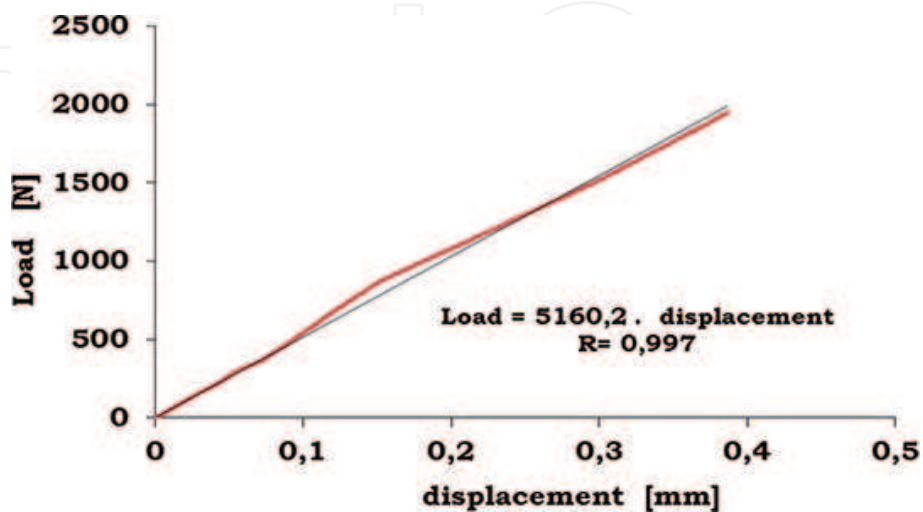


Figure 3. Stiffness of the loading system used for SP tests at laboratory temperature.

Figures 4 and 5 show the influence of displacement monitoring method (crosshead displacement, deflection) on empirical correlations for determination of yield and tensile strengths from the results of SP tests for P92 steel.

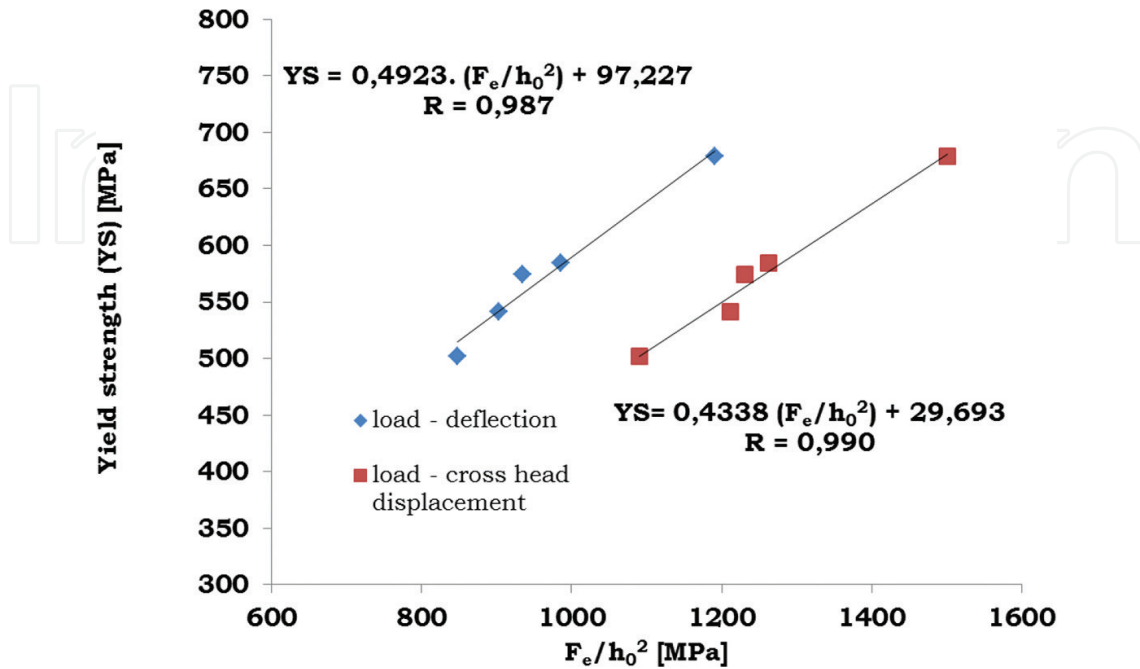


Figure 4. The influence of displacement monitoring on empirical correlation for determination of yield strength from the results of SP tests for P92 steel.

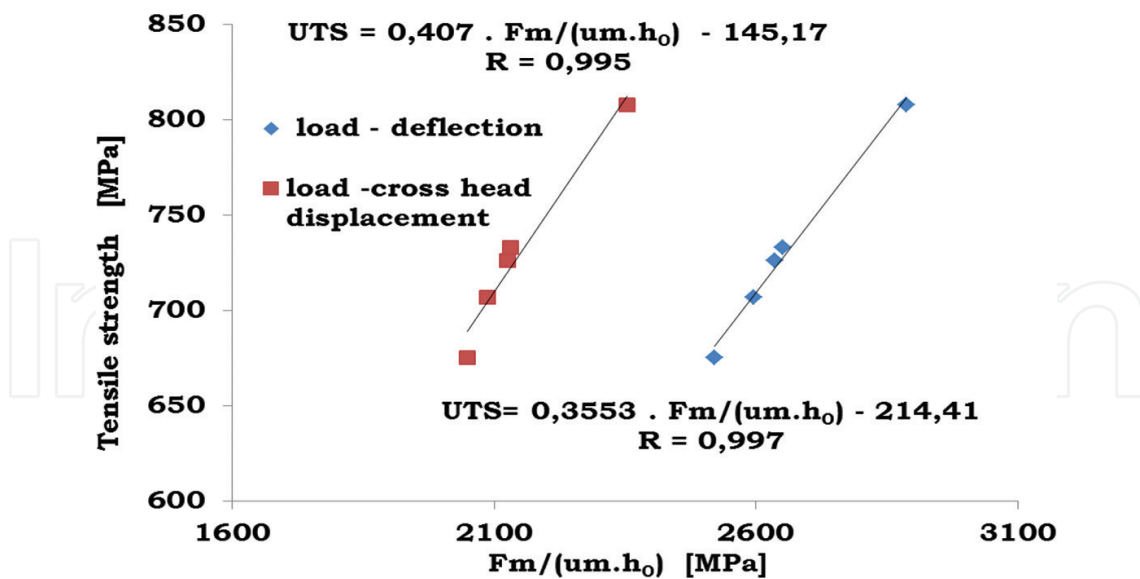


Figure 5. The influence of displacement monitoring on empirical correlation for determination of tensile strength from the results of SP tests for P92 steel.

The results obtained have shown significant influence of displacement monitoring method on both empirical correlations. To explain this difference, the stiffness of the

loading system was deducted from load—crosshead displacement records (see **Figure 6**) of test specimens in as-received state and after heat treatment 1 and heat treatment 4.

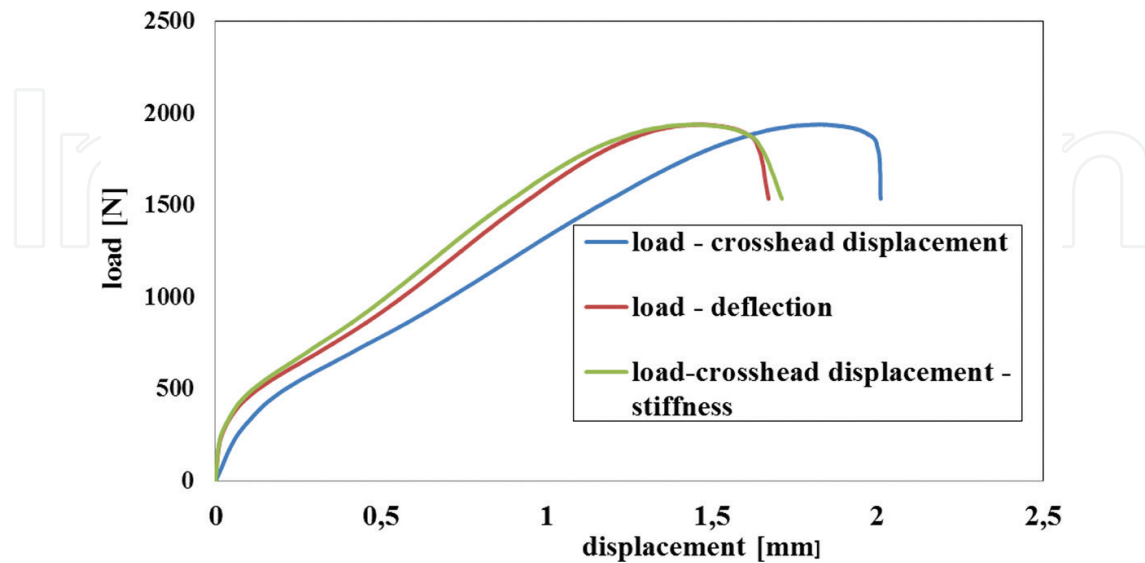


Figure 6. Load-displacement records of the test specimen after heat treatment 4 tested at laboratory temperature.

Figure 7 shows the empirical correlation for yield strength obtained for deflection of test disc monitoring together with parameters F_e/h_0^2 obtained after correction of load—crosshead displacement record for the loading system stiffness.

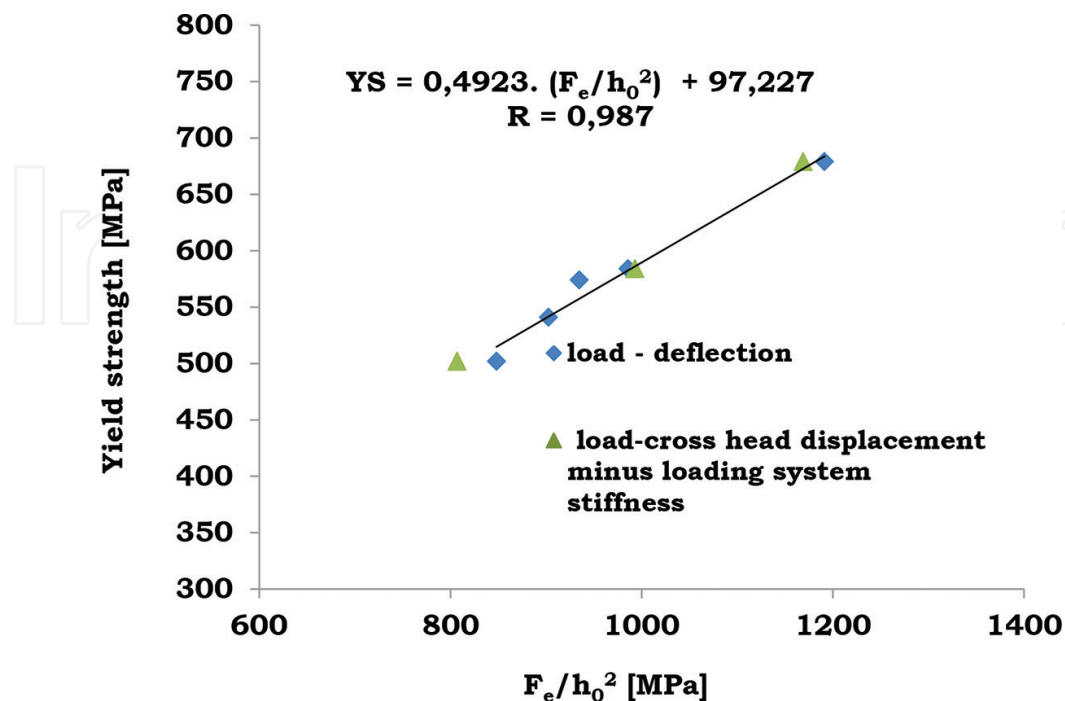


Figure 7. Empirical correlation for yield strength obtained for deflection of test disc monitoring together with parameters F_e/h_0^2 obtained after correction of load—crosshead displacement record for the loading system stiffness.

Figure 8 shows the empirical correlation for tensile strength obtained for deflection of test disc monitoring together with parameters $F_m/(h_0 \cdot u_m)$ obtained after correction of load—cross-head displacement record for the loading system stiffness.

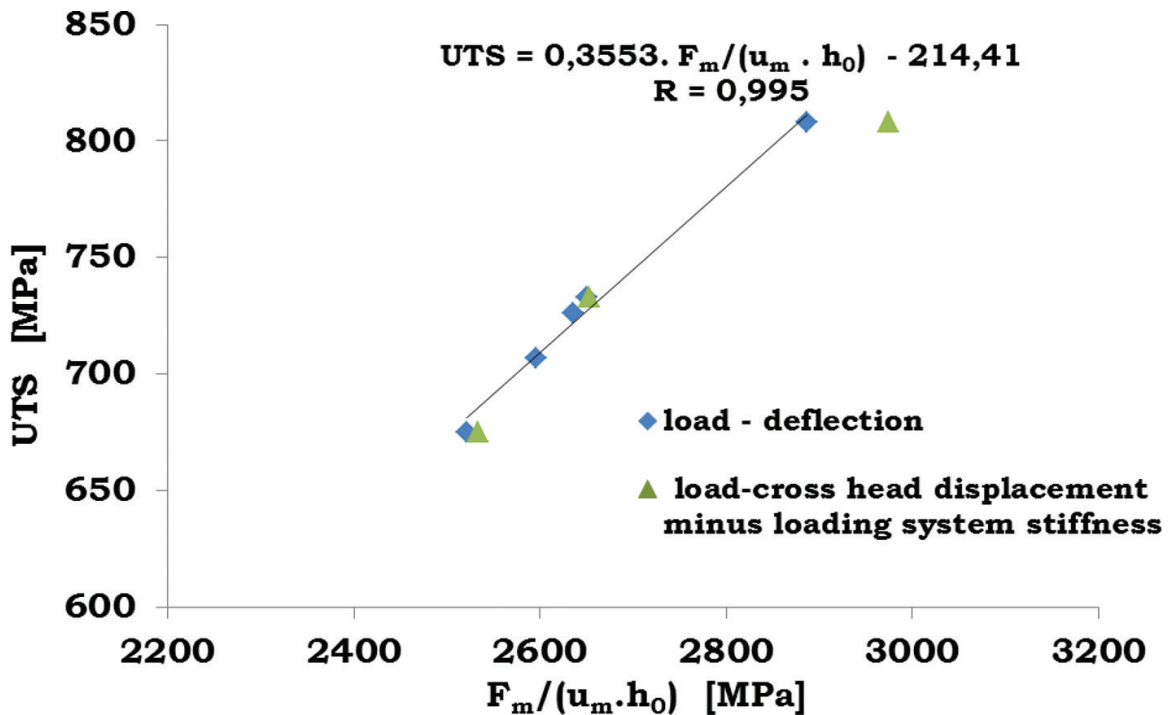


Figure 8. Empirical correlation for tensile strength obtained for deflection of test disc monitoring together with parameters $F_m/(u_m \cdot h_0)$ obtained after correction of load—crosshead displacement record for the loading system stiffness.

4. Conclusions

1. The method used for monitoring displacement during the SP test affects load-displacement record significantly and therefore empirical correlations for the determination of yield and tensile strengths from the results of SP tests.
2. Differences observed between the empirical correlations for determinations of yield and tensile strengths from the results of SP tests obtained on different testing machines can be attributed to the different stiffness of the loading system.
3. Only load- deflection record monitored during the SP test eliminates the influence of loading system stiffness.
4. This fact should be taken into account when revising the document CWA 15627.

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