THE FAILURE OF A NATURAL GAS TRANSMISSION PIPELINE CAUSED BY A THIRD-PARTY DAMAGE

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Abstract: In this paper there are outlined the investigation results of a technical accident that took place recently on a natural gas transmission pipeline, due to the damage of one of the pipes, caused by a third party interference. In order to determine the failure conditions of the pipeline that experienced this technical accident, the authors used more assessment procedures for defects like dent – gouge combinations, generated by third party damages upon this pipeline. The results of the research performed led to the selection and assigning of the measures that have to be taken in order to keep at an allowable level the risk for such events to occur on natural gas transmission pipelines.

Keywords: pipeline, third-party damage, assessment of dent – gouge combinations.

1. INTRODUCTION

The topical statistics, made at European and national level, indicate a significant increase of the amount of technical accidents produced due to third party damages on natural gas transmission pipelines. The reports of the European Gas-pipeline Incident-data Grup – EGIG [1] indicate an amount of about 50 % of the accidents produced by third party damages on natural gas transmission pipelines, while the statistical research described in paper [2] shows that in Romania the amount of this kind of accidents is growing, reaching at present the percent of almost 10 %.

Usually, the anomalies generated on steel pipelines by third party damages are of the following types: a) dents – IN: deviations from an ideal shell geometry of the cross section of the pipework, obtained by the local inward deformation of the pipe wall, not accompanied by metal loss and, consequently, the wall thickness not being reduced; b) gouges – SC: areas of the pipelines where the wall thickness has been locally reduced due to metal loss by a mechanical action (machining); c) dent – gouge combinations – IS: dents which, as it can be seen in Figure 1, have gouges at the base of the deformed area; obviously, anomalies like dent – gouge combinations are the most detrimental, because in their area both the stress concentration effect generated by the change in the cross section configuration of the pipework, and the stress intensification effect generated by the local reduction of the wall thickness take place. The presence of such anomalies on the steel pipelines can significantly affect their loading capacity, determining in very many cases their failure and the occurrence of accidents having important consequences.

Such a technical accident, that occurred recently (June 2010) on a pipeline belonging to the national system of gas transmission pipelines, was the one analyzed in this paper; the accident caused a significant gas leakage, but no fire, human deaths or injuries took place and there was no loss of material goods in the adjacent area.

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The images shown in Figure 2, which reproduce the aspect of the damaged pipeline, highlight the amplitude of the accident. The examination performed at the place of the accident led to the following preliminary hypotheses regarding the way it occurred [3]: a) the failure had an explosive character, the fracture having the characteristics of a ductile fracture, with no fragment displacement from the pipe that failed; b) the failure initiated on a longitudinally welded pipe revealing marks of a third party damage, one could notice many dent – gouge combinations, probably produced by the action of the active elements of a working equipment (excavator, scraper, launcher etc.) upon this pipe; c) anomalies like dents with gouge constituted mechanical stress concentrators, in the area where the initiation and the propagation of cracks under the circumstances of some fluctuations or accidental peaks of mechanical stresses of the conveyed gas was favored.

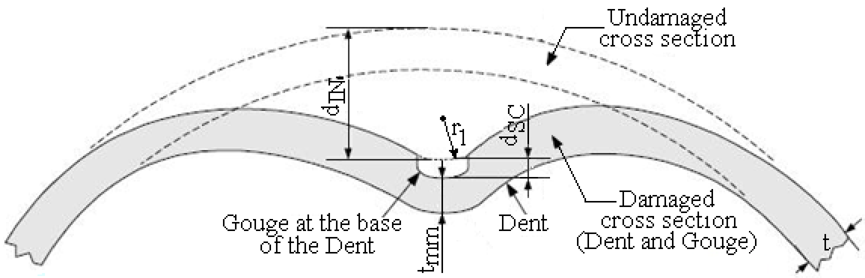

Fig. 1. Modification of the cross section configuration of pipelines in the areas with anomalies like dents with gouges – IS.

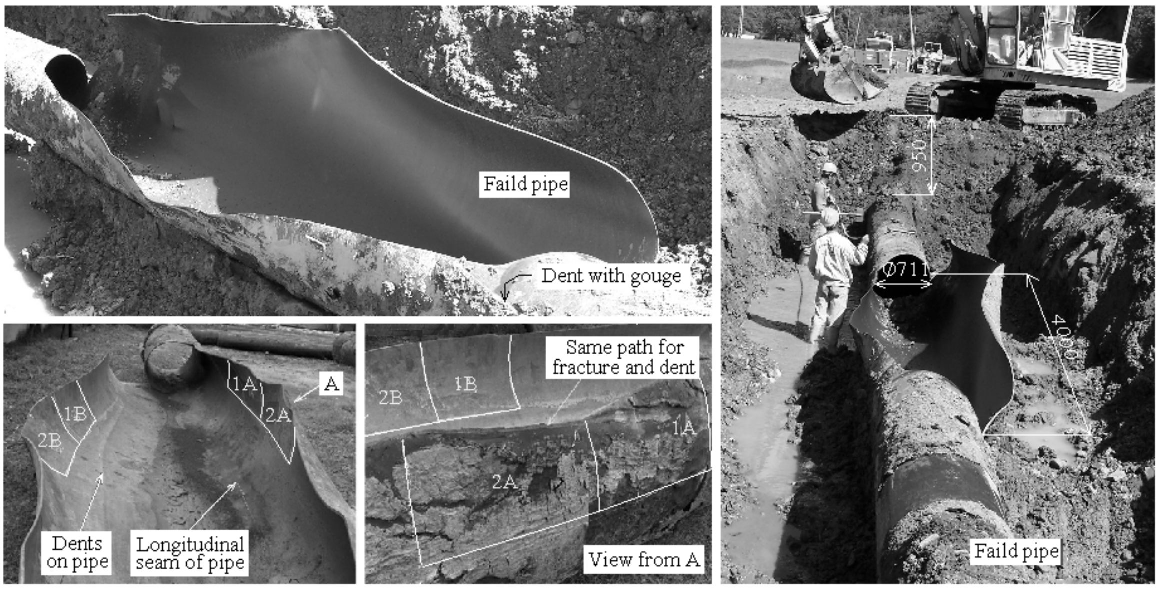

Fig. 2. The area where the explosion of the pipeline occurred and the pipe that failed in service.

2. ASSESSMENT OF THE QUALITY OF THE MATERIAL THE PIPE WHICH FAILED WAS MADE OF

From the pipe (having the outer diameter D_e = 711 mm / 28 in and the wall thickness t = 8 mm) which failed in service and generated the accident, there were taken by oxi – gas delivery six samples: sample 1A, 1B, 2A and 2B, positioned as it can be seen in Figure 1, sample 3, which embedded the paths of the dents with gouge not situated on the fracture route and sample 4, which included the area of fracture arrest. From the samples taken there were delivered and processed specimens for performing chemical analyses, metallographic examinations and mechanical tests necessary for the characterization of the quality of the base material (steel) of the pipe that failed in service. Because, as it can be seen in Figure 1, the failure occurred far from the longitudinally welded joint of the pipe, while the fracture did not propagate up to the butt welds between the pipe that failed and the adjacent pipes, upstream and downstream, on the pipeline, the investigation of these welded joints was not considered relevant for the elucidation of the causes of this failure.

The results obtained on the basis of the chemical analyses, metallographic examination and mechanical tests performed led to the following conclusions [3]:

- The steel the rolled tape was made of used for fabricating the longitudinally welded pipe which failed in service had, as it can be seen examining the data in Table 1, the chemical composition corresponding to X52 – API Spec 5L, specified in the pipeline's design;
- The metallographic structure achieved during the rolling process used for the fabrication of the longitudinally welded pipe which failed in service was adequate, being characterized by: a) aspect of balance structure, of pearlitic-ferrite type, uniform, oriented in the direction of the deformation, with no clearly visible rows, with total lack of the Widmanstatten structure characteristics; b) adequate hardness (162…171 HBS);
- The mechanical properties evinced by tension tests confirmed the fact that the rolled tape structure used for the fabrication of the longitudinally welded pipe which failed in service was adequate; as it can be seen examining the data in Table 2, the mechanical properties (yield strength $R_{t0,5}$, ultimate tensile strength R_m) corresponded to the provisions in API Spec 5L for the X52 steel, and the elongation (percent in 2 in) A_{2in} was only a little lower than the minimum value specified for this steel;
- The fracture toughness of the tape used for the fabrication of the longitudinally welded pipe that failed in service, expressed by the impact energy *KV* (at 0 °C), determined by the notched bar impact bending test, had as a result adequate values (individual values *KV* = 54,7…56,0 J and the average value *KV* = 55,6, at the temperature of 0 °C), superior to those necessary for the material to have a ductile behavior during fracture and to have the ability to stop the unstable propagation of possible cracks initiated during the operation of the pipe ($KV_a \geq 40$ J).

Table 1. Results of the analysis regarding the chemical composition of the pipe material.

Sample	Chemical composition, wt %										
	C	Si	Mn	S	P	Al	Cr	Ni	Mo	Cu	Other
1A	0.20	0.22	0.67	0.034	0.019	0.042	0.07	0.06	0.009	0.021	-
2A	0.17	0.21	0.68	0.020	0.025	0.037	0.05	0.02	0.0	0.019	-

X52 Steel – API Spec 5L	Chemical requirements for heat analyses, wt %				
	C	Mn [a)]	P	S	Other
Welded pipe non-expanded	max.0.30	max.1.35	max.0.030	max.0.030	[b)]
Welded pipe cold expanded	max.0.28	max.1.25	max.0.030	max.0.030	[b)]

a) for each reduction of 0.01 percent below the specified maximum carbon content, an increase of 0.05 percent above the specified maximum manganese content is permissible, up to a maximum of 1.45 percent for X52; b) Nb, V, Ti or combinations thereof, may be used by agreement between purchaser and manufacturer

Table 2. Results of the traction test of the pipe material.

Sample / Direction	Specimen	$R_{t0,5}$, MPa	R_m, MPa	$R_{t0,5}/ R_m$,	A_{2in}, %
1B / Longitudinal	1BL	506	575	0,88	15,0
2A / Longitudinal	2AL	405	530	0,76	19,0
	2AL	416	546	0,76	19,4
Average – Longitudinal direction		**442**	**550**	**0,80**	**17,8**
1A / Transversal	1AT	410	547	0,75	16,6
	1AT	476	558	0,85	19,2
2A / Transversal	2AT	432	546	0,79	15,0
	2AT	421	553	0,76	16,8
2B, / Transversal	2BT	415	529	0,78	13,0
	2BT	409	541	0,76	21,0
3 / Transversal	3T	460	559	0,82	16,2
4 / Transversal	4T	473	546	0,87	15,0
Average - Transveral direction		**437**	**547**	**0,80**	**16,6**
X52 Steel – API Spec 5L		**358÷530**	**455÷730**	**max 0,93**	**min 20**

- The longitudinally welded pipe that failed in service and led to the occurrence of the accident revealed signs of damage caused by a third party, the anomalies like dents with gouge existing on it being probably produced by the contact with the active elements of a working equipment (excavator, scraper, launcher, etc.). The metallographic analyses and the hardness tests performed showed with a level of high confidence that these anomalies were the cause that determined the failure of the pipe, because: a) when the anomalies were produced, the geometry of the pipe locally modified, the dents with gouge acting as mechanical stress concentrators; b) the process of removal by splinting of the material at the base of the dents, which led to the appearance of gouges determined the local reduction of the wall thickness, its increase in roughness and strong cold straining of its shallow layer; as a consequence the mechanical strength of the pipe decreased, and the stress concentration effect determined by the presence of the anomalies increased, while the crack resistance of the pipe material at the base of the gouges decreased significantly due to the strengthening by plastic deformation.

3. ASSESSMENT OF ANOMALIES SUCH AS DENT – GOUGE COMBINATIONS FOR THE PIPE THAT FAILED IN SERVICE

For assessing transmission pipelines that experience anomalies such as dents – IN, gouges – SC or dents with gouges – IS, which resulted due to third party damages, there are applied procedures based on the principles formulated in [4]. For assessing anomalies of IS type existing on the pipe that failed in service and generated the technical accident analyzed within this paper there were drawn up and used assessment procedures at all three levels recommended in [4].

3.1. The Level 1 Assessment procedure of the IS anomalies

For the level 1 assessment of IS anomalies that corresponds to a conservative assessment, based on the application of a succession of criteria that require a minimum data and information amount regarding the pipeline or the analyzed pipeline element, the procedure recommended by [1] can be used if the following conditions are fulfilled: a) the calculation criteria and relations used while designing the pipeline comply with the pertinent norms and standards; b) the material (steel) the pipes of the pipeline are made of have their toughness properties specified; c) the pipeline can assimilate with a cylindrical wrap whose geometry fulfills simultaneously the criteria 168 mm $\le D_e \le$ 1050 mm and 5 mm $\le t \le$ 19 mm, is made of steel pipes which simultaneously fulfill the conditions $R_{t0,5} \le$ 482 MPa and $R_m \le$ 711 MPa and is subjected only to the load produced by the pressure of the conveyed gases (the action of other additional loads can be neglected); d) the IS anomaly being assessed is far from other anomalies existing on the pipework and from the structural discontinuities on it (welded joints, fittings or branches etc.).

Because, as it results from the previously stated, the conditions are fulfilled, there was applied such a procedure, following the next steps:

Step 1. There were determined the initial data that assure the quality characterization of the new (designed) pipeline, determination of the pipeline state at the moment of the anomaly assessment and the estimation of the future state of the pipeline at the end of the future corroded condition (after the assessment is performed), divided into the following categories:

- data regarding the constructive characterization of the pipeline the anomaly was found on: the outer diameter of the pipeline D_e = 711 mm, the nominal or furnished thickness of the component (adjusted for mill under tolerance as applicable) t_{nom} = 8 mm;
- data regarding the characterization of the operating technical conditions of the pipeline: design pressure of the pipeline p = 4 MPa, current operating pressure of the pipeline p_{op} = 2.5 MPa or the minimum and maximum value of the pressure cycles during the operation of the pipeline $p_{\min}$ and $p_{\max}$, number of the pressure cycles till performing the assessment N_{pt} = 18500 (determined considering that the pressure cycles are diurnal, and the pipeline had been operated continuously since commissioning, in 1959 and till the accident took place, in 2010) and the number of future pressure cycles (after the assessment is performed) N_{pv} = 0 (because the pipe that failed in service was replaced), the value of the design factor F = 0.407 (determined as an effective value, considering p = 4 MPa and $R_{t0,5}$ = 437 MPa – see Table 2); the value of the welded joint factor Z = 1 (because the anomalies whose gravity is assessed are not on the welded joints or in the very next proximity), the minimum operating temperature $T_{\min}$ = 0°C, the additional wall thickness, necessary for supplemental loads (from loads other than the inner pressure) t_{sl} = 0 mm;
- data regarding the mechanical properties of the steel the pipeline element is made of: modulus of elasticity and the minimum specified values (by the standard that settles the steel grade quality the pipes are made of for the yield strength $R_{t0,5}$, the ultimate tensile strength R_m and the impact energy KV at the minimum operating temperature or the effective values of these properties, determined by tests; as it was shown before, the values of these characteristics are: E = 205 GPa, $R_{t0,5}$ = 437 MPa, R_m = 547 MPa and KV = 55.6 J at $T_{\min}$ = 0°C;
- data regarding the uniform modification of the wall thickness due to corrosion: uniform reduction of the thickness (metal loss) from the commissioning till the time of the assessment $LOSS$ = 0 mm (the state of the

pipe that failed in service was impeccable, with no damage caused by corrosion), the uniform reduction of thickness (the future corrosion allowance) (after the assessment) FCA = 0 mm (because the pipe was replaced during the pipeline correction works after the accident);

• data regarding the characterization of the geometry of the anomaly being analyzed: length of the dent (extension in the longitudinal direction) L_{IN} = 900÷1200 mm, width / circumferential extension of the dent C_{IN} = 300…400 mm, depth of the dent measured when the component is pressurized d_{IN} and depth of the dent measured when the pipeline is not pressurized $d_{IN} = d_{IN0}$ = 25…40 mm, maximum depth of the gouge d_{SC} = 0.3…0.9 mm, wall thickness at the base of the gouge t_{mm} = 7.1…7.7 mm, the bending radius at the base of the dent r_1 = 50…70 mm, distance to the nearest weld joint L_w > 800 mm, distance to the nearest major structural discontinuity L_{msd} > 1500 mm (determined by taking into account that, in the vicinity of the area where the failure took place, the pipework didn't have any discontinuities such as branches, tees, isolating valves etc.);

Step 2. It was determined the uniform wall thickness away from the damage (determined by thickness measurements at the time of the assessment) $t_{rd} = t_{nom} - LOSS$ = 8 mm, the wall thickness in the future corroded condition $t_c = t_{rd} - FCA$ = 8 mm and the gouge depth at the end of the future corroded condition $d_{SCf} = d_{SC} + FCA$ = 0.3…0.9 mm.

Step 3. It was checked if the following conditions were fulfilled:

$$t_{mm} - FCA \ge 2.5 \text{ mm}; \quad (1)$$

$$t_{mm} - FCA \ge 2.5 \text{ mm}; \; L_w \ge \max[2t_c; 2.5 \text{ mm}] \text{ and } L_{msd} \ge 1.8\sqrt{D_e t_c}; \quad (2)$$

because the conditions were fulfilled, the next step was undertaken.

Step 4. It was determined the intensity of the membrane hoop stresses in the pipe wall σ_{cM}, with the formula:

$$\sigma_{cM} = \frac{p_{op}}{Z}\left[\frac{D_e}{2(t_c - d_{SC})} - 0.4\right]; \quad (3)$$

it resulted σ_{cM} = 183.1÷198.7 MPa = (0.419…0.455)$R_{t0,5}$.

Step 5. There were calculated the values of the ratios $k_{SC} = d_{SC}/t_e$ and $k_{IN} = d_{IN}/D_e$ and there were chosen from [4], depending on the value σ_{cM}, the anomaly acceptance diagram – DAA adequate for the assessment of the anomaly; there resulted the values: k_{SC} = 0.0375÷0.1125 and k_{IN} = 0.0352…0.0563 and taking into account the results obtained in Step 4, it was chosen first the anomaly acceptance diagram – DAA with 0.3 $R_{t0,5} \le \sigma_{cM} < 0.5\ R_{t0,5}$, where there were positioned the characteristic points of the anomalies, having the coordinates P_D (k_{IN};k_{SC}). Because, as it can be seen in Figure 3, the characteristic points of the anomalies P_D were situated in the area ***UNACCEPTABLE*** of DAA, it was concluded that the assessment by means of the *Level 1* procedure is unsatisfactory and there must be performed the assessment by more complex procedures. Considering that the maximum operating pressure is p_{op} = 2.5 MPa, it resulted, by using the formula (3), σ_{cM} = (0.262÷0.284) $R_{t0,5}$, it was chosen the anomaly acceptance chart – DAA with $0 \le \sigma_{cM} < 0.3\ R_{t0,5}$, but the result of the assessment was identical to the one previously mentioned.

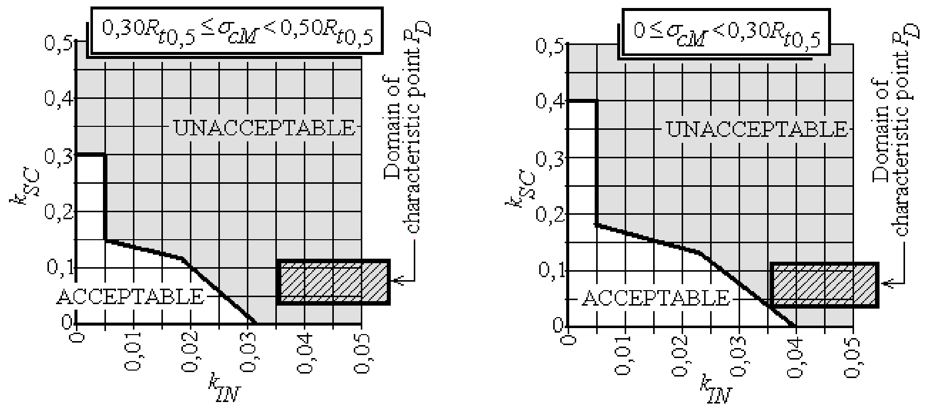

Fig. 3. DAA charts for the level 1 assessment of the IS anomalies of the pipe that failed in service.

3.2. The Level 2 Assessment procedures of the IS anomalies

For the level 2 assessment of the IS anomalies, which corresponds to a more detailed assessment and which leads to results more accurate than those obtained by applying the level 1 procedure, the necessary initial data are the same as those in 3.1, the fulfillment of the same conditions as those while using the level 1 procedures is imposed, but the procedures require the undertaking of some calculations which rely on more rigorous models. Because, as it results from the previously mentioned, the application conditions which were fulfilled, and the results obtained by using the level 1 procedure imposed it, the authors of this paper transposed in a software (called *EVINSC*) the level 2 procedure recommended by [4] and, by means of this, followed all the steps foreseen by this procedure:

Step 1, Step 2 and Step 3. The initial data were checked, it was determined that, as in the case of the application of level 1 procedure, $d_{IN} = d_{IN0} = 25 \div 40$ mm; $t_{rd} = t_{nom} - LOSS =$ 8 mm, $t_c = t_{rd} - FCA = 8$ mm and $d_{SCf} = d_{SC} + FCA = 0.3 \div 0.9$ mm, and the conditions (1) and (2) are fulfilled; also, by analyzing the data regarding the diurnal fluctuations of the pipeline's operating pressure in the year before the accident, shown in the annex 2 of [3], it was determined that the maximum values of the operating pressure were $p_{\max} \in$ [1.4 MPa; 2.6 MPa], while the minimum were – $p_{\min} =$ 0.5 MPa;

Step 4. The fulfillment of the following conditions was checked:

$$d_{IN} \le 0.07 D_e;\ d_{SC} \le 0.66 t_c; \tag{4}$$

because both conditions are fulfilled, the next step was undertaken.

Step 5. It was determined the maximum allowable working pressure *MAWP*, considering only the effect produced by the reduction in wall thickness of the pipe wall due to the gouge having the depth d_{SC}, by using the formulae:

$$MAWP = \min[MAWP_C; MAWP_L],\ MAWP_C = \frac{2R_{t0,5}FZ(t_c - d_{SC})}{D_e - 0.8(t_c - d_{SC})} \text{ and } MAWP_L = \frac{4R_{t0.5}FZ(t_c - t_{sl} - d_{SC})}{D_e - 1.6(t_c - t_{sl} - d_{SC})}, \tag{5}$$

the results obtained are synthesized in Table 3; because $MAWP \ge p_{op}$ and $MAWP \ge p_{\max}$, the next step was undertaken.

Table 3. The values of *MAWP* for the pipe with IS anomalies which failed in service.

Depth of the gouge d_{SC}, mm	0.3	0.5	0.7	0.9
Maximum alowable working pressure *MAWP*, MPa	3.9	3.8	3.7	3.6

Step 6. There were determined the values of the remaining strength factor *RSF*, by using the formula:

$$RSF = \frac{2}{\pi}\left(1 - \frac{d_{SC}}{t_c}\right)\arccos\left[\exp\left(-\frac{C_1 C_3}{C_2^2}\right)\right], \tag{9}$$

where C_1, C_2 şi C_3 are defined with the relations, valid if E and $R_{t0,5}$ are input in MPa, d_{SI}, d_{IN0}, d_{SC} and t_c – in mm, and *KV* – in J:

$$C_1 = \frac{31.78\pi E}{\sigma_{ref}^2 d_{SC}};\ C_2 = Y_1\left(1 - \frac{1.8 d_{IN0}}{D_e}\right) + Y_2\left(\frac{10.2 d_{IN0}}{t_c}\right);\ C_3 = 0.020935 KV^{1.7544}, \tag{10}$$

$$\sigma_{ref} = 1.15 R_{t0.5}\left(1 - \frac{d_{SC}}{t_c}\right), \tag{11}$$

$$Y_1 = 1.12 - 0.23\left(\frac{d_{SC}}{t_c}\right) + 10.6\left(\frac{d_{SC}}{t_c}\right)^2 - 21.7\left(\frac{d_{SC}}{t_c}\right)^3 + 30.4\left(\frac{d_{SC}}{t_c}\right)^4, \tag{12}$$

$$Y_2 = 1.12 - 1.39\left(\frac{d_{SC}}{t_c}\right) + 7.32\left(\frac{d_{SC}}{t_c}\right)^2 - 13.1\left(\frac{d_{SC}}{t_c}\right)^3 + 14.0\left(\frac{d_{SC}}{t_c}\right)^4; \tag{13}$$

the results obtained are synthesized in Table 4.

Step 7. There was determined the allowable remaining strength factor RSF_a = 0.9, this value is recommended by most of the design norms and standards for pipelines and pressurized vessels [3]. Because $RSF < RSF_a$, there were calculated the values of the reduced permissible maximum allowable working pressure of the damaged pipeline $MAWP_r$, at which the pipeline with the IS anomaly could be operated safely (no failure), by using the formula:

$$MAWP_r = MAWP \frac{RSF}{RSF_a}, \tag{14}$$

the values obtained are given in Table 4.

Table 4. *RSF* values for $MAWP_r$, for the pipe with IS anomalies which failed in service.

Depth of the gouge d_{SC}, mm		0.3	0.5	0.7	0.9
Remaining strength factor *RSF*, for depth of the dent d_{IN}, mm =	25.0	0.461	0.370	0.228	0.203
	32.5	0.365	0.291	0.178	0.158
	40.0	0.301	0.239	0.145	0.129
$MAWP_r$, MPa, for depth of the dent d_{IN}, mm =	25.0	2.0	1.6	0.9	0.8
	32.5	1.6	1.2	0.7	0.6
	40.0	1.3	1.0	0.6	0.5
Permissible number of pressure cycles N_c, for depth of the dent d_{IN}, mm =	25.0	17087	6527	1234	567
	32.5	9504	3630	642	295
	40.0	5769	2204	371	170

Step 8: There were determined the maximum pressure cycles which the pipeline with *IS* anomalies could withstand N_c, by using the formula:

$$N_c = 562.2\left[\frac{R_m}{2\sigma_A K_D K_g}\right]^{5,26}, \tag{15}$$

$$\text{with } \sigma_A = \sigma_a\left[1 - \left(\frac{\sigma_{cM,\max} - \sigma_a}{R_m}\right)^2\right]^{-1},\ \sigma_a = \frac{\sigma_{cM,\max} - \sigma_{cM,\min}}{2}, \tag{16}$$

$$K_D = 1 + C_s\sqrt{\frac{t_c}{D_e} d_{in0}^{1,5}},\ K_g = 1 + 9\frac{d_{SC}}{t_c}; \tag{17}$$

the results obtained were also included in Table 4.

Because in all situations considered for the dimensions of the *IS* anomaly it resulted that $MAWP_r < p_{op}$ and $N_c < N_{pt}$ it could be stated with a high level of confidence that the presence of this anomaly was the cause that determined the failure of the pipe that generated the analyzed technical accident.

For the assessment of the *IS* anomaly it was also applied the level 2 procedure, based on the construction of a Failure Assessment Diagram FAD, according to the provisions in [5]; the results obtained led to the same conclusion as before [3].

3.3. The Level 3 Assessment procedure of IS anomalies

Although the assessment by means of level 2 procedures led to relevant results regarding the determination of the causes of the analyzed accident, it was also performed an assessment by a level 3 procedure, which, as it is stated in [4], corresponds to the most rigorous assessment and leads to results better substantiated than those provided by the assessment with the level 2 procedures, the initial data necessary for such an assessment being more detailed and the assessments performed on the base of numerical analyses and simulations, using, for instance, the finite element method.

The procedure applied by the authors was based on the finite element method – MEF, by means of which there was made the analysis of the stress and deformation states (of elastic – plastic type) in the area of IS anomalies of the pipe that failed in service. It was considered the dent - gouge combination model shown in Figure 1, with d_{IN} = 25÷40 mm and d_{SC} = 0.3÷0.9 mm (the same as for level 1 and 2 assessment procedures) and it was determined the pressure at which the burst of the pipeline takes place p_s; the values p_s = 1.0÷2.2 MPa obtained indicated that the previous conclusion regarding the causes of the failure of the pipe that generated the analyzed accident were correct [3].

3. CONCLUSIONS

The running through of this paper leads to the following conclusions of general character:

- the anomalies generated on the steel pipelines by third party damages can significantly affect their loading capacity, causing in very many cases their failure and the occurrence of accidents with important consequences;
- the procedures suggested by the authors are very useful for assessing the remaining mechanical strength of pipelines with anomalies generated by third party damages and for obtaining information pertinent for taking decisions whether to continue their operation or to apply maintenance works;
- for pipelines that are supposed or are known to have been subjected to third party damages there must be elaborated programmes for risk mitigation and for increasing the in service safety, which must include both physical measures and procedural measures; the main such measures are: a) the technical verification of pipelines for finding all the pipes with anomalies (like those that determined the failure of the pipe involved in the accident analyzed within this paper); it is recommended the use with this purpose of the direct assessment, which consists of the performing of some bell holes (in the places on the pipeline route where there were performed various works or activities) which allow the direct observation of the pipeline state; b) the elaboration and observance of a program for preventing the damage of pipelines caused by third parties (external interferences), drawn up by consulting the guide in Annex 5 in [3]; c) permanent supervision of pipelines in order to find possible gas leakages and to mark the pipeline route.

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