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An approach for reliability analysis of defected pipelines

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ABSTRACT - The paper describes a possible approach, that has to be considered as a first and preliminary approach in a more general scenario, for the evaluation of the reliability of pipelines whose failure is relevant from the point of view of economic and ecologic consequences. The target of the activity is to evaluate the failure probability of a defected pipeline in normal operating conditions, on the basis of the results of NDE carried out by an inspecion pig.

1. FOREWORD

The pipelines are the fundamental means of transport of hydrocarbons in every industrialized country. Such a system allows to convey quickly great quantities of crude or fine oil to the refineries or the storage and distribution areas.

The pipelines are in general constructed following the soil orography and they are buried at a minumum depth of 1.5 m, in order to reduce the enviromental impact. Such a circumstance causes evident in-service inspection difficulties; on the other side the inspection of the oil pipelines is of a great importance because of the critical consequences (pollution and danger for people) of an incidental failure.

In the present paper the structural reliability analysis was developed starting from the results of non destructive examination (carried out by means of magnetic flux leakage inspection pig) and evaluating their interactions with the acting stresses and the material characteristics.

The proposed approach lead to a result that is not to be interpretated as a purely physical property of the pipeline itself, but it is rather a nominal value yielding a measure of the designers confidence in the structural performance. In other words, a calculated nominal reliability level depends on the method and the procedure applied, including probabilistic modeling of load, capacity, knowledge uncertainty and applied assumptions. Hence, the results from the reliability analysis should not be directly associated with a frequency interpretation of observed failures, but may be regarded as a comparative measure, partly dependent on the amount of information available [1].

2. STRUCTURAL RELIABILITY ANALYSIS

2.1 General

The approach is described making reference to a specific pipeline evaluated in normal operating conditions: the pipeline is 50 km long, made by 10" nominal diameter seamless pipes, with a thickness equal to 7.09 mm; the service pressure varies along the line starting from 45 bar at the beginning (pump station) and ending at 7 bar; the material is a carbon steel classified as API 5L Gr. X52.

2.2 Identification of the failure modes

According to an agreement achieved by 63 operating oil companies in Western Europe, the occurrence of possible oil spillages can be ascribed to 5 different causes [2]:
- mechanical failure;
- operational incidents;
- corrosion;
- natural hazard;
- third party activities.

The statistical data provided by all the companies indicate that the major cause of incidents is the corrosion of pipes which typically occurs with two different phenomenologies: the general corrosion, characterized by wide areas of thickness reduction, and the pitting corrosion, characterized by small areas in which the reduction of thickness occurs.

It should be noted that the conventional NDE methodologies measure with sufficient accuracy just the defects characterized by a reduction of thickness, such as corrosion or mill defects. Therefore only these typologies of defect have been considered in the analysis and in the methodology hereafter described the reliability of the structure is to be considered with reference to the possible evolution of corrosion defects in the normal operating conditions. In other word the present analysis gives a reliability assessment of pipelines in terms of risk of failure due to a local reduction of the pipe thickness.

2.3 Identification of the significant variables and their statistical characterization

The variables of the problem may be separated into 4 groups:
1- Mechanical properties of the material: tensile strength (σ_R), yield strength (σ_Y), elastic modulus (E), toughness (CTOD);
2- Geometrical features of the pipeline: thickness and diameter;
3- Applied stress: pressure;
4- Dimensions and distribution of defects: number and position of the detected defects along the line; depth and length of each defect.

The process variables are of aleatory type (their quantitative determination is uncertain) and they can be characterized through proper statistical distributions.

For each input variable of the problem a sensitivity analysis was performed in order to evaluate their significance in the calculation, to give more weight to the more significant variables and to allow for some semplification of the analysis without reducing the results accuracy.

This preliminary analysis was performed using PD 6493 level 2 approach [3]. In this analysis a set of possible values of each variable was considered and the influence of their variability in terms of reserve factor, i.e. distance to the limit condition [4], on the results was evaluated.

As regards the applied load, i.e. internal pressure, according to the data supplied by the companies which manage oil pipelines, the values of the operating pressure depend on the operating conditions but, as a certain condition is applied, no significant variation occurs; therefore the sensitivity analysis was not carried out on the pressure variable.

With regard to the defects, the type, the number and the position along the line were assumed as known data, without uncertaintes: only surface corrosion defects were considered; the number and the location of the defects were assumed as indicated in the NDE reports; infact very small defects, even if present, do not influence the structural integrity evaluation; on the other hand the large defects, with high "structural integrity significance", are surely detected.

The results of the sensitivity analysis can be summarized with the following statements:

- the typical variability range of mechanical properties do not significantly affect the results;
- the typical variability range of diameter of pipes do not affect the results; with regard to the thickness, its variability strongly affects the results;.
- the uncertainties on the measured dimensions of a defect, considered with reference to the performance specification of the standard NDE instrumentation used for the inspection of pipelines (intelligent pigs), strongly affect the results.

Considering the results of the sensitivity analysis, the input variables were treated with three different approaches: deterministic, semiprobabilistic and probabilistic.

a) <u>Deterministic variables</u>
  - Pressure: maximum operating value, with a linear variation along the line taking into account the reduction of pressure.
  - Young modulus: from technical literature 206000 MPa.

b) <u>Semiprobabilistic variables:</u> all the variables were considered with a normal distribution [5]; the reference value was chosen as the upper or lower band value evaluated as the mean $\pm 2\times$ standard deviation (SD).
  - Diameter: from the pipes supply specification the variability is within the 1% of the nominal value; the SD was assumed equal to 1/4 the variability range [6].
  - Yield strength and tensile strength: a series of transversal tensile tests were carried out and the mean value and the SD were evaluated.
  - Toughness: three CTOD tests were carried out and the minimum result was assumed for the calculation, according to PD 6493/91.

c) Probabilistic variables: all the variables were considered with a normal distribution. Their mean value and SD were taken into account in the calculation.

- Thickness: the mean value was taken equal to the nominal one and the SD was assumed 1/4 the variability range of the thickness, equal to 12.5% of the nominal value, as specified in the pipes supply specification.
- Depth and length of defects: for each defect the mean value of depth and length was taken equal to the one recorded by NDE instrument (note that the depth of the defect is provided by the NDE reports in terms of percentage of the nominal thickness) and the SD was correlated with the mean value making reference to the performance inspection equipment specification, to the technical judgement and to the field experience. Fig. 1 shows an example of a curve indicating the standard deviation of the depth for general corrosion defects.

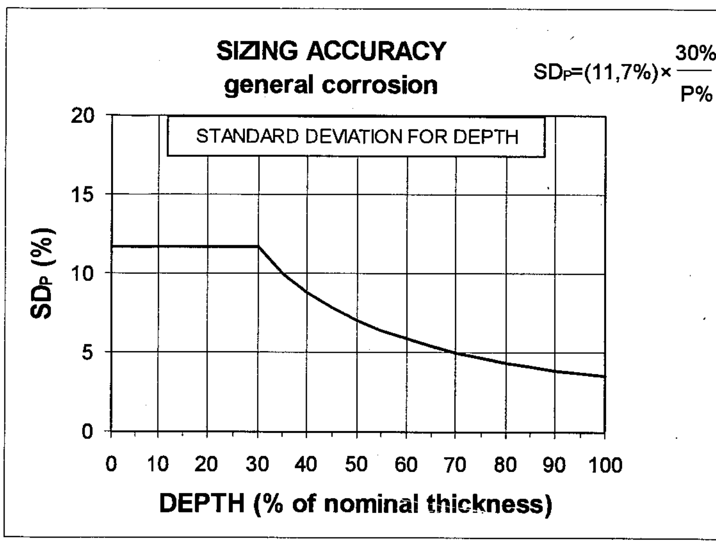

FIGURE 1

2.4 Evaluation of failure probability

The evaluation of the failure probability (FP) was performed in two steps.

1) The first was the elaboration of what we have called "responce surfaces" (RS). These surfaces were elaborated according to the following criteria: if a defect of known dimensions (length and depth) is present in a zone of pipeline whose characteristics (in terms of local diameter, pressure, mechanical properties) are known, the FP of the defect coincides with the probability that in that point the local wall thickness is so small that the defect is unstable.

At this point, for each zone of the pipeline characterized by different pressure and nominal thickness a RS was built in accordance with the following methodology: for each defect having depth included within 21% and 100% of nominal thickness and length from 0 to 300 mm, the FP as specified above was evaluated. The flaw assessment was made in accordance with the document PD 6493. Fig 2 shows an example of a RS.

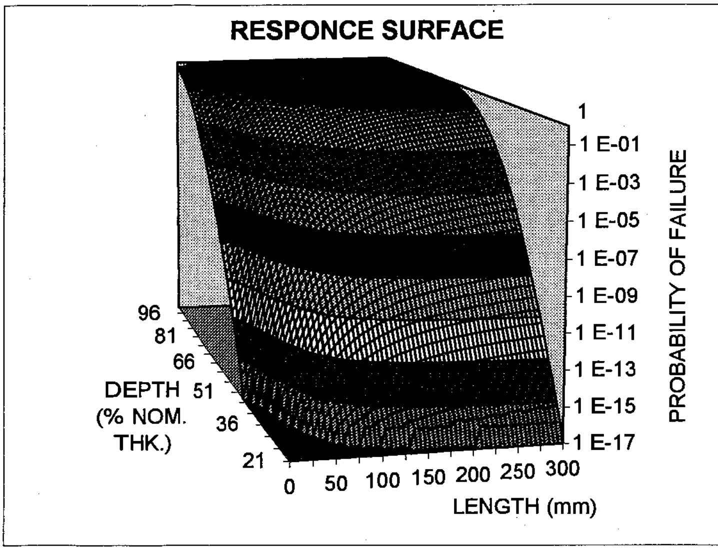

FIGURE 2

From the shape of the RS some considerations can be made:

- the FP is negligible since the depth of the defect reachs the 30% of nominal thickness; on the other side there is almost failure certainty for defects with great depth (FP = 1);
- for mid values of both depth and length the surface grows very quickly and the FP changes from negligible to high values with an exponential trend.
- it should be noted that, in accordance with PD6493 methodology, defects with very small length are not critical even if the depth is very near to the local thickness; this fact can be understood considering that the stress distribution in the section containing the defect is not significantly modified by the presence of the defect itself: the defect will not provoke the burst of the pipe but it will leak as its depth becomes exactly equal to the local thickness. This situation, not contemplated in PD6493, is well known as "leak before break"; in these cases (defects 0÷5 mm long and 100% of nominal thickness deep) the FP is equal to 0.5; infact the real local thickness has the 50% probability to be greater than its mean value.

2) The second step consisted in a simulation analysis of the defected pipeline performed by Monte Carlo method. In every simulation a configuration of the pipeline consistent with the results of the inspection (in terms of number and position of defects along the line and of recorded values of the defects dimension) was created; in each configuration the detected defects were considered in their position with randomized dimensions with reference to their statistical representations (see fig.3 for a view of the defects detected by NDE on the line). For each defect a probability of failure FP was evaluated by means of the RS. At the end of each simulation the global probability of failure (POF)

of the defected configuration of pipeline was evalutated considering the FP of each single defect as an indipendent event.

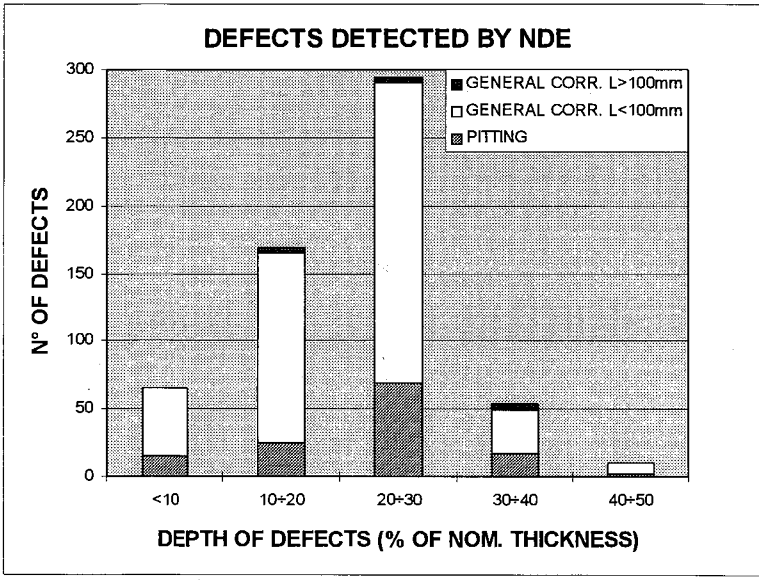

FIGURE 3

It should be underlined that the RS used for each evaluation depends on the defect location along the pipeline and therefore on the local pressure.

A preliminary analysis has led to the definition of a number of simulations adequate in order to obtain a proper POF distribution.

In figg. 4-5 the results of a 1000 simulation analysis is shown; the results are reported in the form of frequency istogram and cumulative distribution. As characteristic values of the pipeline reliability the mean value and the 95% confidence value were considered.

3. CONCLUSION

A reliability assessment methodology for pipelines on the basis of NDE results was described. This methodology was applied to four existing oil pipelines with the purpose to define a classification of their relative reliability with the primary intention to support the decisions regarding the maintenance operations and the future inspection strategy. Moreover the results of the analysis can be compared with required target reliability levels calibrated against the consequences of possible failures.

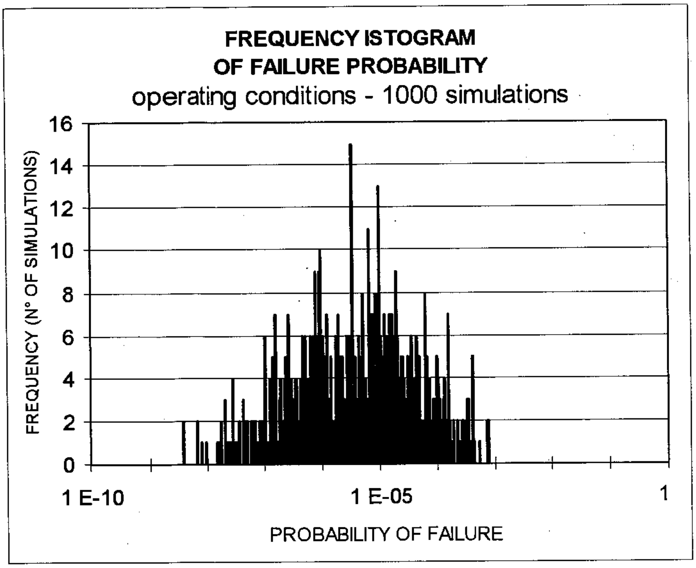

FIGURE 4

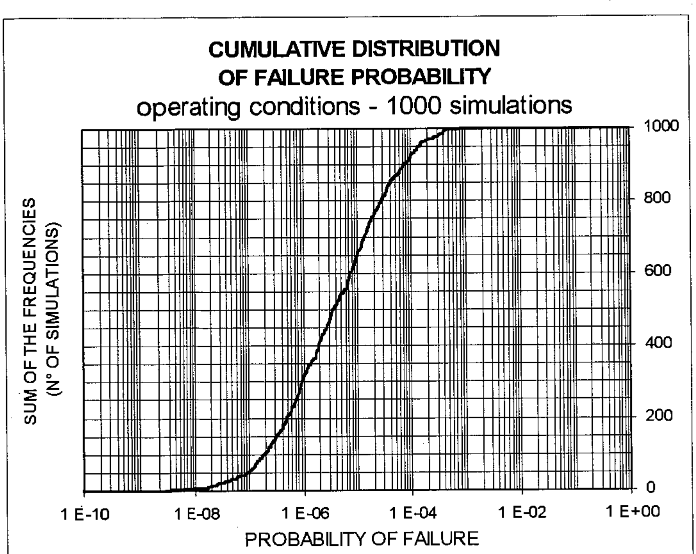

FIGURE 5

REFERENCES

1. Kim J. Mørk & Øisten Hagen 1995. Reliability-based pipeline design and maintenance. *Seminar on industrial applications of probabilistic method*: 163-172. Paris: France.

2. Berry, K.G., Bianchini, M., B. Muller & P. Pries 1994. Performance of oil industry cross-country pipelines in western Europe; statistical summury of reported spillages - 1993. *Concawe report* 5/94.

3. BSI PD 6493. 1991. Guidance on methods for assessing the acceptability of flaws in fusion welded structures.

4. S. Reale & L. Tognarelli 1992. Applicazioni della procedura R6 per l'assicurazione della qualità nella progettazione e nelle ispezioni in servizio di componenti strutturali. *Rivista Italiana della Saldatura* 6/92: 529-535.

5. Pitner, P., Riffard, T., B. Granger & B. Flesch 1993. Application of probabilistic fracture mechanics to optimize the maintenance of PWR steam generator tubes. *Nuclear Engineering and Design* 142: 89-100.

6. I. Sprung & V.A. Zilberstein 1992. Superheater and reheater boiler tube-life estimation. *Materials Evaluation* 8/92: 966-990.