Assessment of the condition of pipelines as a basis for economic and safety-related optimisation

Introduction

Being covered with soil, the condition of buried pipelines cannot be directly and easily monitored. Moreover, their overall condition changes so slowly that it appears as if they do not change at all.

It is only when a network has been monitored over a long period of time that it becomes obvious that the condition of such systems also changes slowly but continuously.

In view of the fact that a buried pipeline transportation network is an asset of extremely high value and - in particular when used for carrying dry sweet gas - has a practically unlimited service life, it is certainly worthwhile both to assure the integrity of the lines by documenting and evaluating their condition and to optimise inspection, maintenance and repair expenses as well as the control of these expenses.

The following paper outlines the basic features of a system designed for the documentation and assessment of the condition of pipelines. It has to be emphasized, however, that a condition assessment focussing exclusively on the impact of corrosion, although covering an important parameter, is a great deal away from a realistic and comprehensive condition assessment.

Concept of a condition assessment method

According to the relevant European standard EN 1594 [1], high-pressure lines are designed exclusively for the load case 'internal pressure'. In reality, however, pipes are exposed to a greater variety of loads (**Figure 1**). The approach adopted in the standard is nevertheless appropriate because, compared with the high internal pressure, the effects of the other loads are so low that they can be ignored. They usually lead to an increase in stresses and a decrease in the load-bearing capacity of an order of magnitude of just 5 %, compared with the effects of the internal pressure. If individual loads or load spectra reach significant orders of magnitude, e.g., because a pipeline covered by only a thin layer of soil is exposed to extraordinarily high traffic loads, dynamic loads are applied in the proximity of the line (rammer), or because the load-bearing capacity is reduced by severe corrosion, integrity of the line will have to be proven for the combination of all loads and not only for individual selected influencing factors such as the internal pressure or corrosion.

Assessment methods

In view of these requirements, the question arises which assessment method should be used for determining the condition of a pipeline. It is of course possible, using exact calculation methods, to locally and temporarily determine the load to which a high-pressure line is subjected as a result of the action of the given load spectra. However, this approach would not only be extremely time-consuming, because complex calculation methods would

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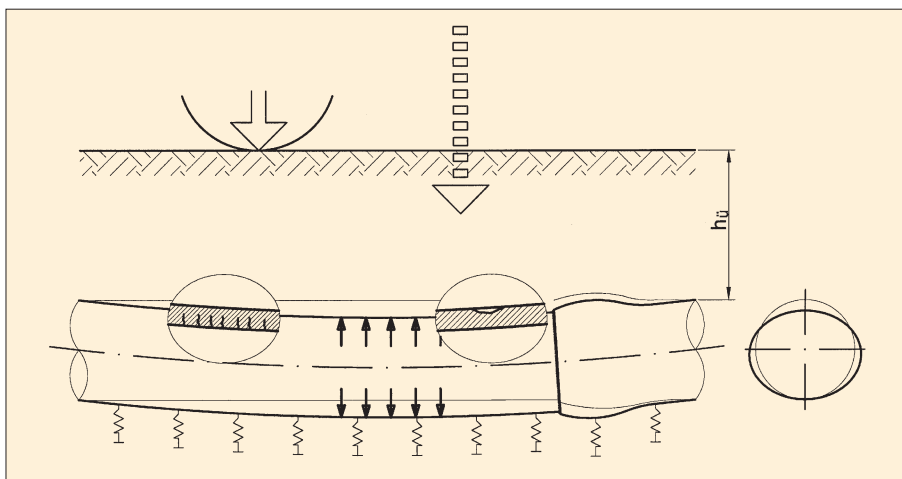Tel. +49(0)341/443-2740

Fig. 1: Special Loads on PH-Pipelines

have to be used (for example, the finite-element method), but would also not be able to cover certain effects, such as a thinner soil cover, with the help of a deterministic stress analysis. In addition, with the deterministic concept, the

only if probabilistic concepts and risk-based methods are used, that is, if the failure probability is determined [2 to 5]. A failure probability can be determined for all influences affecting a system or reducing its load-bearing capacity.

Figure 2 shows the failure probability for a pipeline subjected to internal pressure. It is determined from the distribution of the load and from material characteristics. **Figure 3** gives an example of the determination of the failure probability related to the soil cover of a pipeline based on empirical values from network operators.

Figure 4 gives a schematic summary of these assessments and shows that all influences have been assessed with the help of a standardised concept. The system is of modular construction and is able to take into account all influencing factors acting on the system. It also allows to accurately take into account fluids having a particular impact on the material (for example, raw oil or sour gas). The overall failure probability determined has to be compared to a limit value, and measures will have to be taken only in cases where this limit value is exceeded.

In **Figures 5, 6** and **7**, the results are given for the assessment of the condition of a section of a high-pressure gas pipeline exposed to different influences. A comparison of Figures 6 and 7 clearly shows that it is possible to directly study the reaction of the system caused by a change in the data. While the nominal pressure of the system causes the permissible failure probability to be exceeded at individual points in Figure 6, it can be seen that the limit values will just not be reached if an operating pressure of 20 bars is entered.

It will be obvious to any expert in this field that this approach permits to optimise maintenance programmes and operating processes. The companies Verbundnetz Gas Aktiengesellschaft (VNG) and Dr.-Ing. Veenker Ingenieurge-
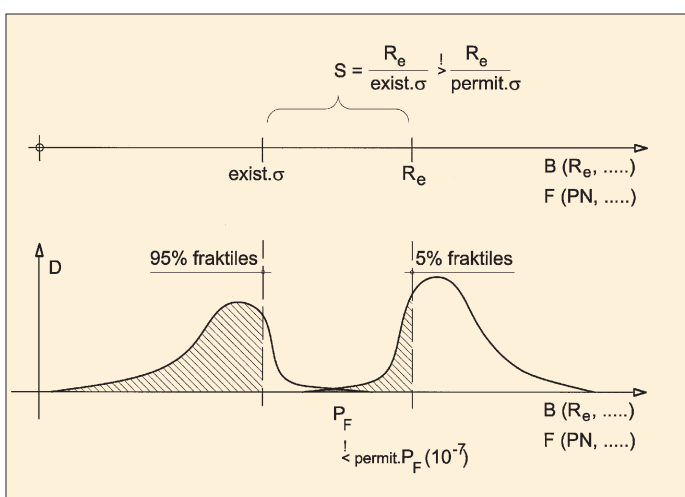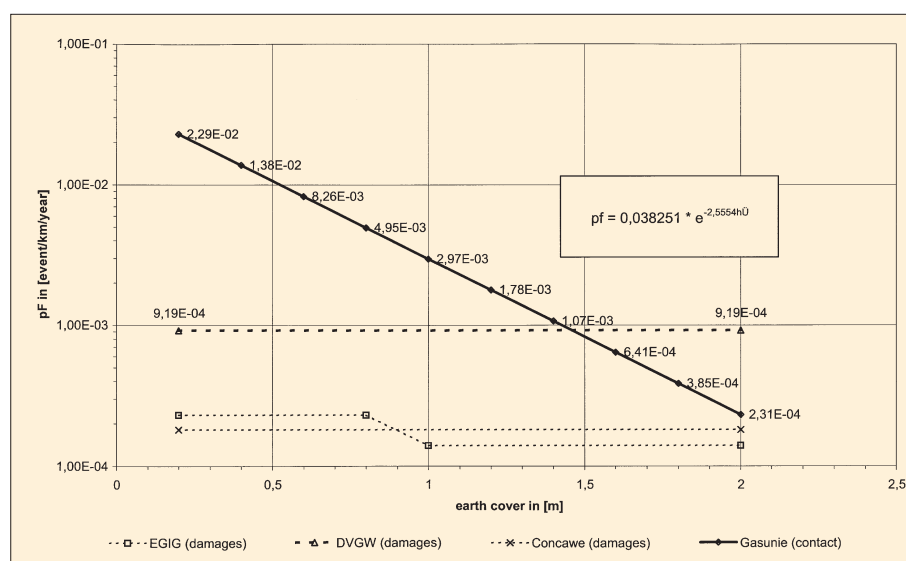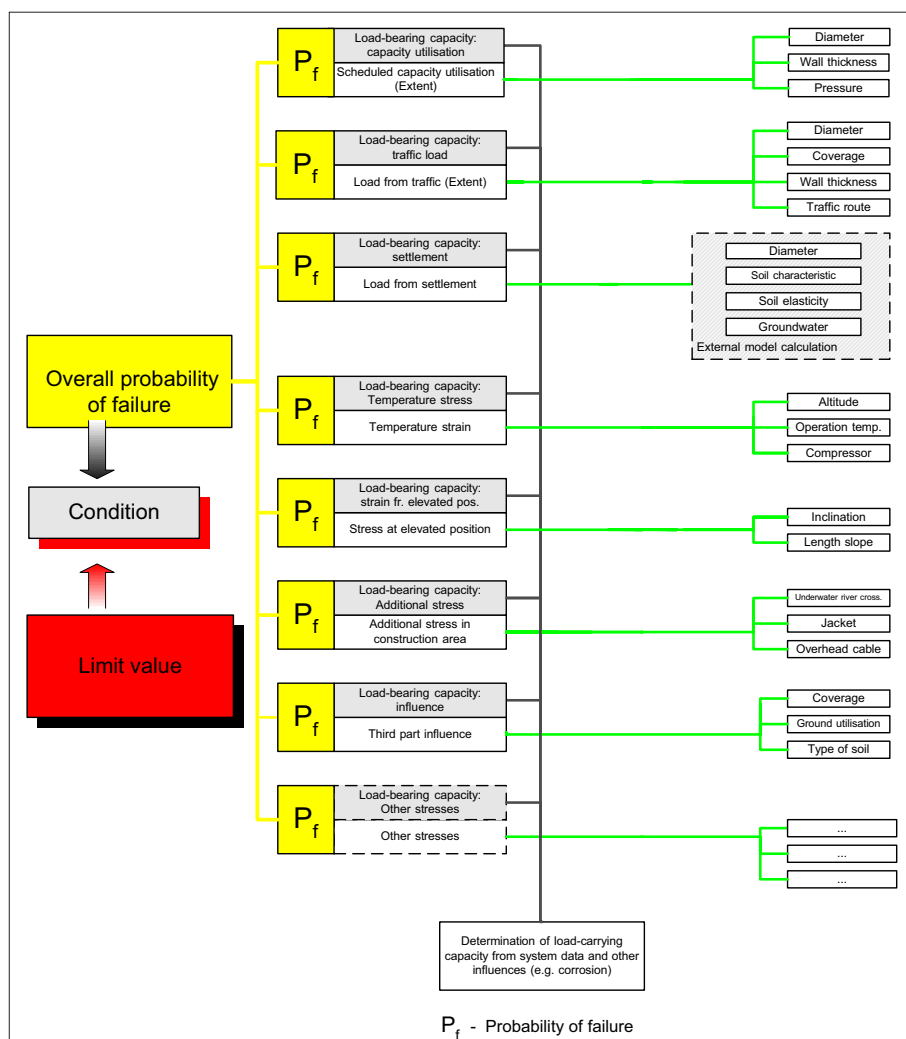

Fig. 2: Determination of failure probability for the load case internal pressure

maximum permissible stress would already be reached, because the load-bearing capacity of the line is utilised to the maximum extent by the internal pressure so that further load-bearing reserves could be tapped only by reducing the factors of safety.

Neither would an assessment of the different loads and load spectra with the help of points or ratings yield satisfactory results, because, on the one hand, these methods are affected by the subjectivity of the assessing person and, on the other hand, because they do not permit to achieve conclusive results which equally and comprehensively allow for such different influences as corrosion, dynamic loads and soil covers of reduced thickness.

A comprehensive and appropriate condition assessment can be achieved

Fig. 3: Probability for damage by a third party

Fig 4: Evaluation Structure (Extract)

making this assessment, although this standard's limitations are already mentioned in its foreword. It is not possible to apply the standard in the proximity of welds where special components, such as elbows, are concerned. Neither can the standard be used in cases where the line is subjected to additional loads apart from corrosion. Moreover, when taking a detailed look at the standards and the associated literature, it appears as if not all influences have been duly taken into account. Thus, for instance, no allowance at all is made for the extent to which a corrosion site extends in the circumferential direction, and also the material, in particular the ductility which is of importance for the dispersion of stresses in the area of a corrosion site, is completely neglected in B31G.

The Finite-Element Method (FEM) represents a calculation method that allows to assess precisely the losses in wall thickness caused by corrosion, thus making it no longer necessary to resort to parameters of an empirical nature for decision-making. Applying the FEM method yields significantly different results from those based on ASME B31G. **Figure 8** shows the separation curve for geometrical parameters according to B31G separating permissible wall thickness losses from impermissible losses. In addition, curves have been plotted in this diagram that have been obtained with the help of
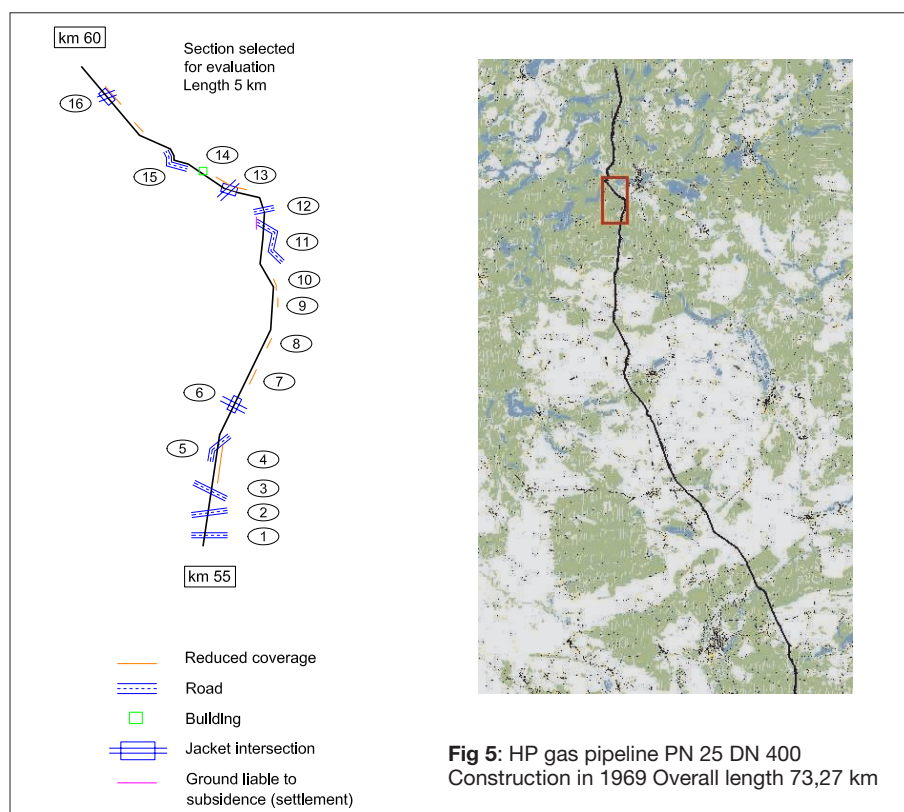
sellschaft (Veenker) have developed this programme and have had it certified by the regulators, so that the programme can be generally applied to pressure lines.

Assessment of corrosion losses

Among the influences shown in Figure 1, corrosion certainly is of greatest importance. Still, it needs to be emphasized again that assessing the effects of corrosion will give a complete and realistic picture of the condition of a pipeline only if such an assessment takes into account all the other influences acting on the pipeline.

Though the use of intelligent pigs has made it much easier to locate external and internal reductions in wall thickness of lines caused by corrosion and other influences, no conclusive and appropriate method has been available so far for evaluating the effects of corrosion and for determining whether repairs will have to be carried out immediately or whether the stability of the line concerned is not yet at risk. The standard ANSI ASME B31G is generally applied for

Fig 5: HP gas pipeline PN 25 DN 400 Construction in 1969 Overall length 73,27 km

precise FEM calculations. They take into account, in particular, the size ratio of a corrosion site in the longitudinal and circumferential directions and the effect of different materials. It is obvious that applying B31G to cases of long loss-affected sites yields uneconomical results, which may be acceptable, whereas the results according to B31G for short loss-affected sites lead to dangerous and unsafe misjudgements.

Calculating and assessing wall thickness reductions with the help of FEM involves lengthy calculations. A network operator may in certain cases not be expected to use such an approach when a decision has to be made quickly after a wall thickness reduction has been located. Therefore VNG and VEENKER have developed the assessment programme KaRo, which is based on neuronal networks and derives its results from a large number of FEM calculations that were conducted earlier. Taking into account all parameters involved, this programme is able to determine within a few seconds whether an area with a reduced wall thickness may be left untreated or at which permissible pressure the line may continue to be operated without the risk of failure. Naturally, the programme is capable of processing the large amounts of data that are commonly produced when lines are examined using intelligent pigging. To visualise the results, areas with a reduced wall thickness that do not affect the nominal pressure at which a line is operated are represented in the form of corrosion classes. Major areas with a reduced wall thickness, which no longer permit to operate the line at the nominal pressure, are represented as singularities, and the reduced permissible pressure in this area can be directly seen from the diagram (**Figure 9**).

Corrosion forecast

While corrosion assessment is one of the most important tools within the framework of a condition assessment, it is of little value if it does not involve corrosion forecasting. Intelligent pigging usually identifies such a large number of areas with reduced wall thickness that no operator is able to examine or rehabilitate them immediately afterwards.

In many cases, only the result of a single intelligent pigging run is available. Moreover, the results of intelligent pigging are unfortunately not accurate to such an extent that a highly reliable corrosion forecast can be made from a comparison of the corrosion sites found in two pigging runs. Therefore it is necessary to adopt a theoretical approach in this case.
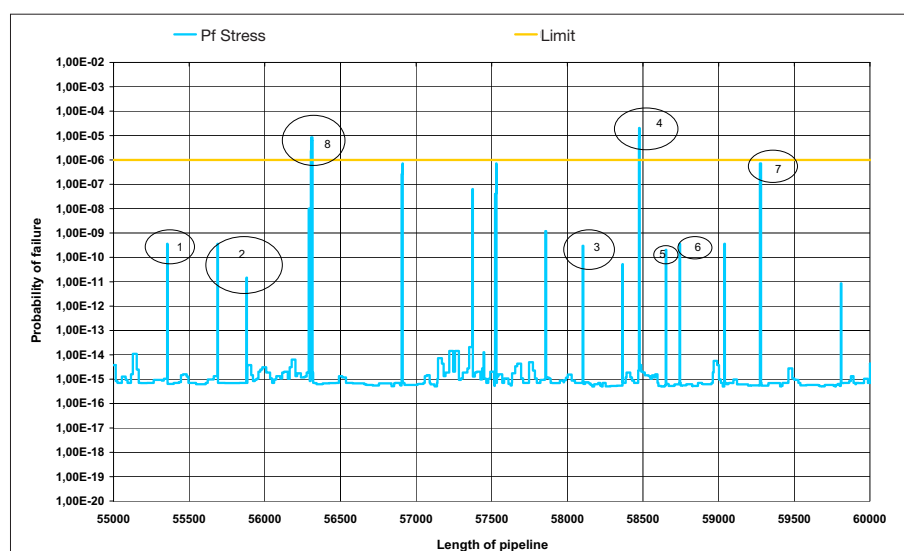
Fig. 6: Evaluation Result: Failure probability of pipeline
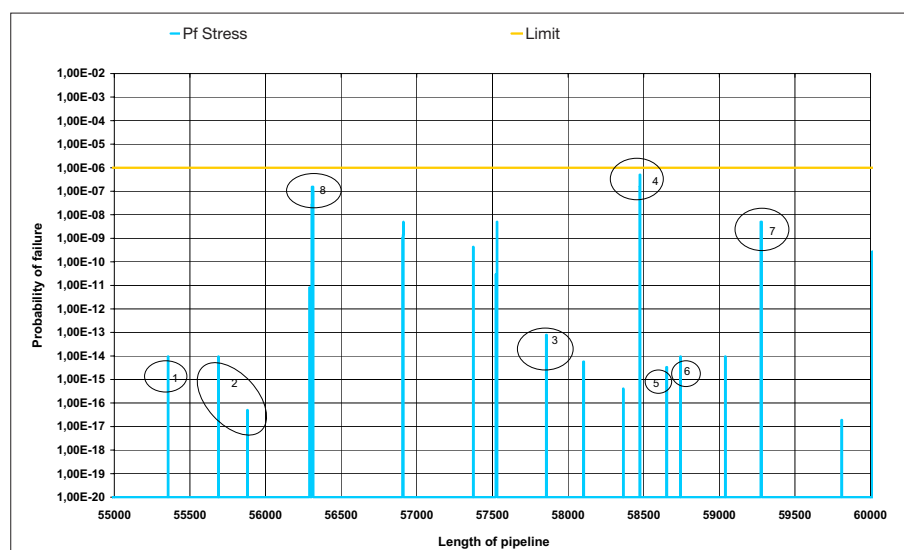
**Fig. 7**: Evaluation Result: Reduction of presure to PN 20

Making generally valid corrosion forecasts, which are safe but not too conservative, is possible only to a limited extent. At best, it will be possible to cover the most important influences by algorithms, which can then be queried from an expert system and further processed by specialists. The extensive literature, from which only excerpts are quoted in [6 to 15], and the experience gained by corrosion protection experts of network operators allow to achieve more defined predictions so that useful results can be obtained for the corrosion forecast according to the flow chart in **Figure 10**. Listing all the algorithms used would be beyond the scope of this paper. They have been implemented in the computer programme KaRo [16] that can be used for determining the period of time at which an untreated loss-affected section can be operated safely at full nominal pressure. The rate of reduction

in wall thickness due to a two-dimensional or singular corrosion site ranges from 0.01 mm/a (e.g. corrosion sites in pipes with properly functioning cathodic protection) to 0.3 mm/a (e.g. corrosion sites with limited cathodic protection) and even up to extreme values of 1.2 mm/a (e.g. in pipes exposed to electric influences).

Application of condition assessment in day-to-day operations

At VNG, technical condition analysis has been integrated with a geographic information system (GIS). This approach allows for centrally documenting the current condition of lines, comparing the lines with each other, and optimising any repair expenditures required. A distinction has been made between the assessment of fittings and other devices
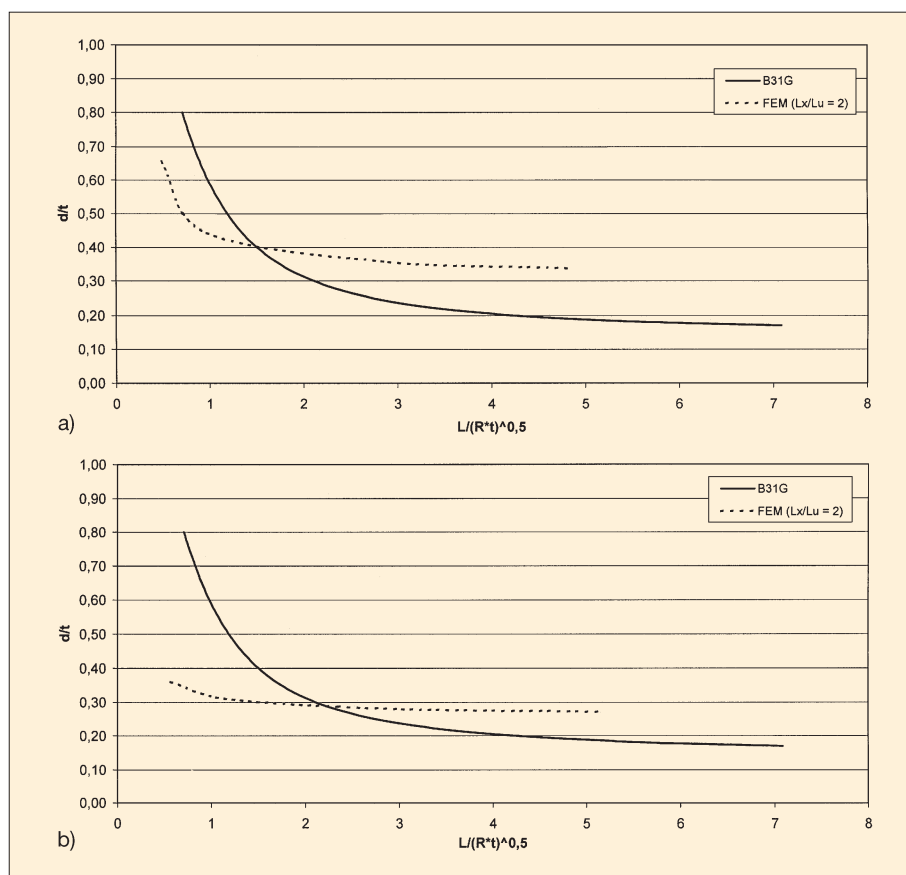
Fig 8: Comparison of the border curves for wall-thickness reductions pipe DN 400, a) material StE 290.7, b) material StE 480.7

(singularities) and the assessment of the linear part of a line, the failure probabilities determined being rated against the risks (limit values) generally accepted by the public.

At present, a total of 26 singularities are covered. Of this number, 16 can be assessed directly, irrespective of the line assessment, with respect to the rehabilitation measures they require. Apart from the singularities, 44 types of raw data are collected for the line

assessment, 32 thereof being directly used for assessment purposes, while the remaining serve as additional information which is available for further evaluations and for the purposes of an information system.

Data collection is performed at first based on the information available in existing records.

An essential prerequisite is, however, that the surveying records are up to date and properly reflect the existing situation.
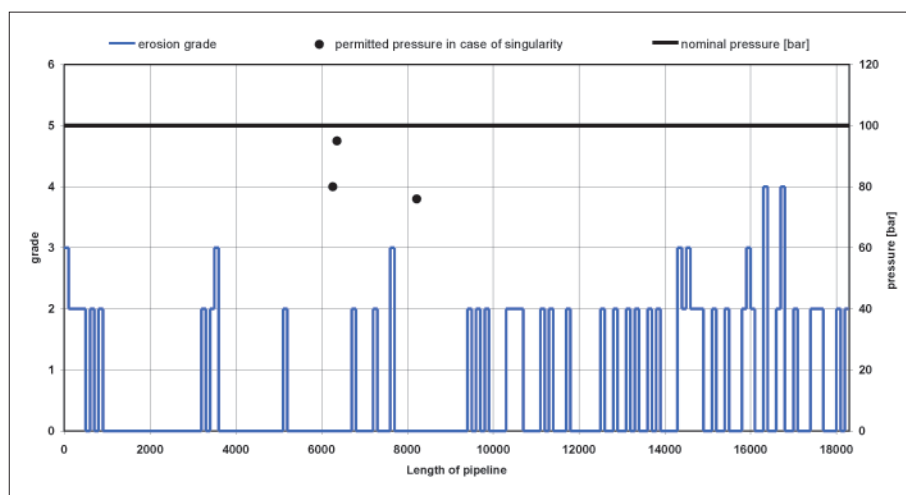
Further important data sources include:
▷ Acceptance certificates and other certificates (pipe book),
▷ Study reports and operating records,
▷ Measurements of cathodic protection (from database WinKKS),
▷ Evaluation of soil chemistry and soil mechanics.

For the time being, no time-consuming soil examinations for determining the soil aggressiveness and soil mechanics are carried out. The evaluation is performed by experts based on available topographic and geological maps and an assessment of the impact of current soil uses.

In this way, linking relevant raw data, possible wall thickness reductions caused by corrosive processes are determined in the form of potential corrosion losses (expert system "Corrosion").

Integrated condition analysis

Since the quality of the input or raw data is of decisive importance for the result of an assessment, it will not be necessary in each and every case to take immediate action if an assessment comes to the conclusion that lines are in a critical condition. It will rather be important to focus on the quality and source of the raw data. This means that costly and extensive re-examinations (setting up pipe current measuring points, intensive search for defects, soil and material samples, excavations...) will be confined only to certain sections of a line. More accurate raw data will generally yield more accurate results concerning the safety of the pipeline.

Internal inspections are an excellent tool for obtaining more precise line data. This means that the data supplied by intelligent pigs are used as raw data in the technical condition analysis, and extensive re-examinations and excavations are no longer required on account of the high quality input data. The data collected by measurement supply reliable information about the exact location of reductions in wall thickness, accumulations of corrosion spots, and the quality of circumferential field welds and pipes. The absence of such localisation data may lead to a global deterioration of entire line sections.

Circumferential field welds in older high-pressure gas pipelines frequently do no meet present-day quality requirements on account of the welding techniques and testing methods used at the time when the pipeline was constructed. They pose a safety risk only in very few cases, however. Within the framework of a research project carried out together with

Fig. 9: Result of corrosion assessment with KaRo: erosion grade

the TU Mining Academy in Freiberg, a calculation method based on fracture mechanics theories has been developed. This method allows for a rapid and safe evaluation of old welds exhibiting defects. With this programme for the evaluation of old welds, VNG has created a further tool for an integrated condition analysis (**Figure 11**).

The integrated condition analysis developed by VNG allows to dispense with complex rehabilitation measures based on the relevant codes and standards (conservative) and to use a condition-based approach for maintenance and repair instead, including

▷ Limitation of rehabilitation efforts to the elimination of precisely evaluated and localised acutely endangered defective sections,

▷ Incorporation of the remaining defective sections in a phased rehabilitation programme based on existing service life reserves, and

▷ Cost reductions to the level needed for meeting operational and supply safety requirements.

Experience

VNG's network of high-pressure lines has grown over the years so that it is now comprised of lines of a varied age structure measuring about 7200 km (**Figure 12**). About 50 % of the network lines are suited for pigging. Based on the construction standard, VNG has adopted the following approach for evaluating its lines.

Lines suited for pigging:

▷ Internal inspection with intelligent pigs

▷ Sections for which wall thickness reductions have been detected are evaluated based on limit values using FEM analysis and neuronal networks (programme KaRo)

▷ Estimation of the remaining useful service life with the help of corrosion forecasts for pipeline sections where cathodic protection is not yet completely ensured

▷ Determination of immediately necessary measures and development of a phased programme for the rehabilitation of the remaining defective sections

Lines not suited for pigging:

▷ Development of the technical condition analysis on the basis of a documentation review (available information) and of the results of measurements of the cathodic protection system

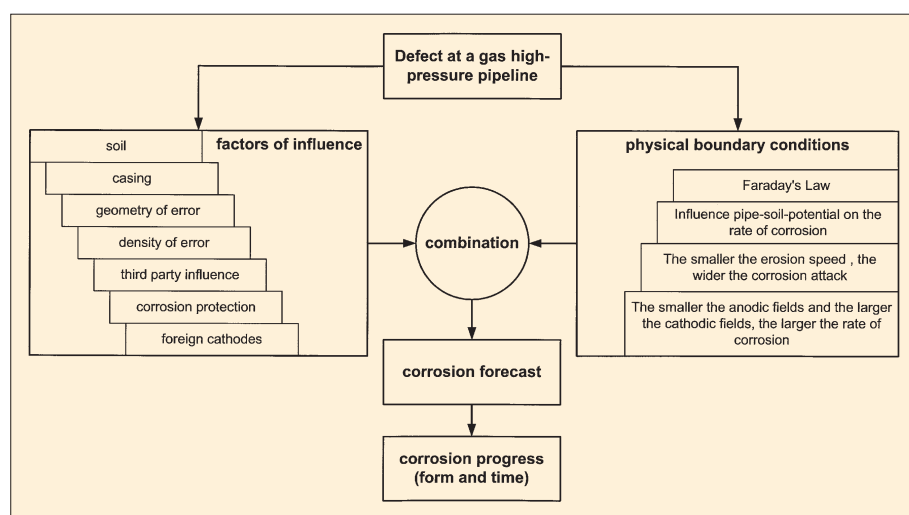▷ Prioritisation of determined defective sections on the basis of probabilistic evaluation methods

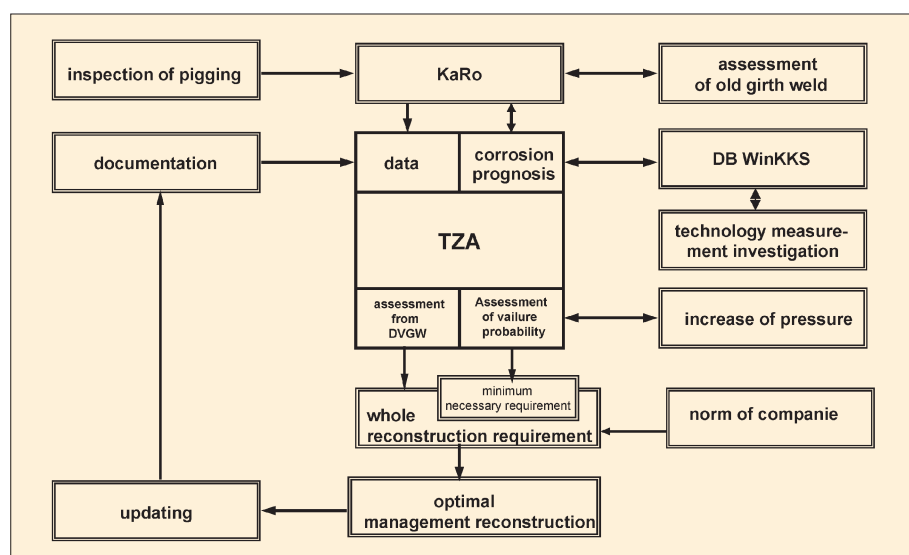
Fig. 10: Formulation for a corrosion forecast

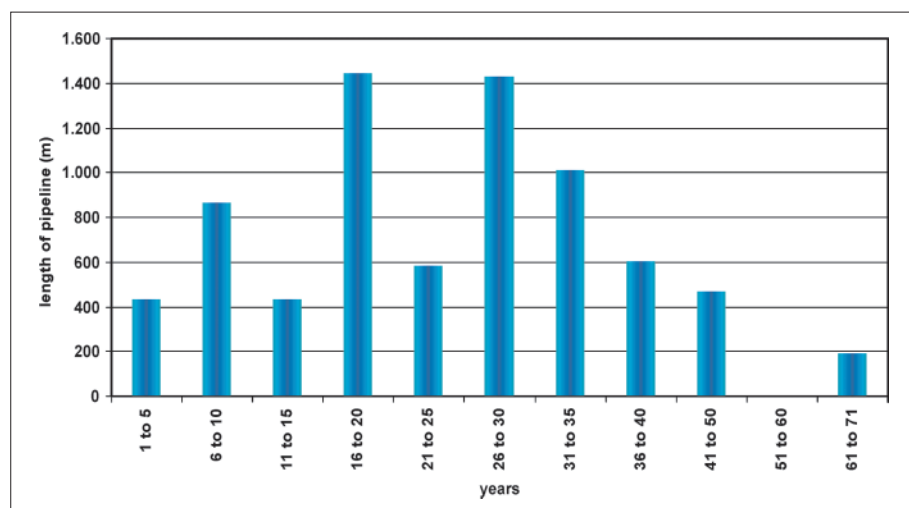**Fig. 11**: Integrated condition analyses

Fig. 12: Age-structure of pipeline network VNG of 2001

> Determination of immediately necessary measures and development of a phased programme for the rehabilitation of the remaining defective sections

So far, VNG has pigged pipelines with a total length of 985 km and evaluated pipelines with a total length of 2664 km with the help of technical condition analysis.

The fact that occurrences of failures and faults in the high-pressure pipeline network of VNG show a downward trend in spite of reduced line rehabilitation expenditure is clear evidence of the effectiveness of the approach adopted.

VNG's experience concerning the technical condition analysis for long-distance high-pressure gas pipelines demonstrates that an assessment of pipelines and comparison of results is generally possible in spite of the varying quality of data available for individual lines. Furthermore it is obvious that necessary rehabilitation and maintenance expenditures can be determined and optimised, thus leading to a cost-effective solution.

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