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"Deformation of Cemented Casings - Case Studies, Analysis, and Pressure De-rating Procedure."

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7 Summary and Conclusions

Cemented casings showing unexpected deformations are observed in a number of wells. These deformations are mostly associated with swelling or creeping formations, like clay and salt, sometimes as a result of production from reservoirs or operations with storage caverns and sometimes as a result of geotechnical reasons, for example, caused by tectonics.

With regard to salt caverns it has to be evaluated whether the deformed cemented casings still fulfill the requirements in terms of collapse resistance and possibly if tightness is affected.

The objective of the present study is to review the commonly applied design procedure with regard to avoiding casing collapse and to collect and analyze data of observed deformations of cemented casings with a focus on salt formations. Based on responses to the questionnaire that has been circulated among the SMRI membership, as well as on additional activities by PB-ESS, data from a total of 93 wells with observed unexpected deformations were made available. Except for a small number of other types of deformations, mostly cross sectional deformations (ovalisation) were reported. Thus the focus is set on ovalized casings. The majority of reported wells can be assigned to three locations. This opens up the opportunity to identify general dependencies for unexpected deformations.

Collected data are analyzed in terms of adequate safety in the design, safety of the deformed casing, possible relations between ovalisation and safety of the design, ovalisation and depth and location of the observed deformation within the salt section. The main conclusion from this investigation is that no clear correlations can be determined. This leads to the conclusion that site-specific conditions are responsible for unexpected deformations.

Possible causes for unexpected deformations are described on the basis of literature research. They can be assigned to phenomena such as shearing, rupture in tension, axial and lateral compression and bending. With regard to ovalisation of cemented casings, shearing and lateral compression are regarded as responsible in most cases of the available data. Both mechanisms will result in non-uniform loading of the casing. It is currently being discussed how geotechnical conditions, wellbore conditions, casing design and operating history can contribute to non-uniform casing deformations.

If deformed casings are observed, the essential question is whether the well can be operated further. This means the remaining collapse resistance of the deformed casing has to be determined and assessed. This procedure is referred to as de-rating.

A compilation of known procedures in the literature leads to the conclusion that either analytical methods or numerical simulation models are used. Therefore, both methods are being studied in greater detail.

Analytical formulae, which are considered in greater detail in this study, are deduced from the TIMOSHENKO solution for the deflection of oval tubular rings. Applying these formulae, casing deformations can be related to casing stress, which then can be compared to design values of the collapse resistance according to TIMOSHENKO, KLEVER and TANAMO and/or API 5C3. These analytical formulae exclusively focus on the tube (casing). They can be applied for generating graphs showing the relation of casing deformation with regard to external pressure. This enables a rough evaluation of the present casing status with regard to collapse resistance. A selection of graphs for casings frequently used in the cavern industry is presented in Appendix C.

Analytical formulae, which are discussed in this study, are deduced from the KLEVER and TANAMO design formulae or from the TIMOSHENKO solution for the deflection of oval tubular rings as well as its collapse resistance. Applying these formulae, casing deformations can be related to external stress on the casing, which then can be compared to the formation pressure at depth of observed deformation resulting in the determination of a factor of remaining safety. In order to perform this evaluation conveniently a spread sheet was prepared, where after providing the input for casing specifications, geological profile and the observed casing state in terms of maximum and minimum inner diameter as well as thickness, the remaining possible maximum external pressure on the casing is calculated by using the KLEVER and TANAMO design formulae: This value is then compared to the formation pressure as indicated above. The application of a procedure based on the TIMOSHENKO solution for tubing deflection turned out to produce a wider range of calculated safety factors, which indicates a higher uncertainty. Therefore, the stress based procedure according to the KLEVER and TANAMO design formulae is recommended in order to provide a quick evaluation of the observed casing status. If several successive measurements are available, the trend of remaining collapse resistance based on the design formulae can be illustrated and evaluated.

As a consequence of the restrictions of analytical methods, numerically simulation techniques are applied, if a greater level of detail has to be taken into account. A disadvantage of these simulation techniques is that more specific data have to be considered and should therefore be available. The advantage is that the main contributing elements of the load-bearing system consisting of casing, cementation and rock mass can be incorporated in the model, while at the same time different material characteristics can be considered as well as changes of the whole system over time.

Numerical studies presented in this study were performed at the Technical University of Clausthal. Three principal simulation models are applied. In the first type of simulation models, only the casing is taken into account. These models serve to generally validate the technique by comparing the results with those of analytical procedures. Furthermore, simple relations between selected specifications of the casing, such as pre-ovalisation, grade, wall thickness, casing eccentricity and the corresponding collapse resistance, are shown. In the second group of models the cementation is introduced. The general influence of the cementation is studied as well as an eccentric location of the casing in an otherwise excellent cementation. With the third group of models the surrounding rock salt mass is introduced in the simulations. The influence of the loading history is studied, while elasto-plastic behavior is assumed for the casing, visco-elastic behavior for the hardening cement, elasto-plastic behavior of the hardened cementation and visco-elastic behavior for the salt. In addition to the loading history, influences by operation are studied as well as possible patterns of a bad cementation.

The results of the numerical studies clearly point out how important excellent cementation is, as good cementation substantially contributes to the load-bearing. Therefore, the calculated resistance to collapse is much higher if not only the casing has to withstand the loads. Although very conservative assumptions are made for the un-cemented sectors, the results of the numerical simulations indicate that casing deformations may develop very quickly if the cementation is not excellent. The observed relatively high ovalisation of 17% that has been reported in response to the questionnaire can be demonstrated by this kind of specific simulation.

It can be concluded from the results of the numerical investigations that if specific conditions contribute to an unexpected deformation of cemented casings, the remaining collapse resistance can be evaluated in greater detail by applying numerical simulation techniques. However, more detailed site-specific data are necessary.

Based on the findings of the main parts of the study – evaluation of reported casing deformations and analytical and numerical investigation of the remaining collapse resistance due to different basic conditions of the casing – a possible procedure for the evaluation and de-rating of deformed cemented casings is described. The main points reflect

- performance of a rough evaluation of the observed casing state by using analytical or empirical procedures,
- decision on whether to continue the assessment procedure by extended investigations in greater detail by
    - thorough analysis of the current status by taking into account existing data of the location and identification of the need to perform additional logging,
    - review of the casing design,
    - identification of possible causes of the observed unexpected deformation,
    - back-analysis of the current state and calculation of the remaining resistance to collapse,
- assessment of the remaining resistance to collapse,
- recommendations for future operations.

This guideline should be understood as support and not as a binding recommendation.