Design and Analysis of Containments. State of the Art on Introduction of KTA Safety Standard 3401.2

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Abstract

In Germany containments for PWR plants are free-standing steel vessels. Design and analysis of the containments have been performed according to KTA Safety Standard 3401.2 since October 1980. The methods of design practiced and the experience gained over the years are reflected in the above Safety Standard and in the relevant structural analyses.
The aim of this paper is to provide a brief outline of the current status.

1 Safety Standard for Metal Containments

At the 24th Meeting of the German Nuclear Safety Standards Commission (KTA) in June 1980 KTA Safety Standard 3401.2 for the design and analysis of metal containments was adopted. /1/
This Safety Standard is based on the experience gained by the manufacturers, independent experts and authorized inspection agencies over the past decade in assessing the strength of containments and thus replaces all project - related specifications previously required.

The Safety Standard applies to metal containments (MCs) including locks and nozzles. It contains the following sections:

1. Scope
2. Basic principles
3. Load conditions, loads and service limit categories
4. Structural design
5. Structural analysis

The following comments apply to KTA Safety Standard stipulations which differ from those in other standards. The leaktightness of the MC is the primary objective. Proof of leaktightness is considered to have been provided if the results of the structural analysis for service limit categories 0 to 3 show that the allowable stresses are not exceeded. Further verification must be provided by the pressure test prior to commissioning and during inservice inspection when the MC is retested for leaktightness at 0.5 bar overpressure.

If proof is to be provided of the structural stability alone, only those areas of the MC which have an effect on the structural stability will be analysed, using the relevant service limit category.

The load conditions, loads and service limit categories to be considered are shown in Fig. 1. The introduction of service limit categories is new, i.e., all load conditions for which the same limit values apply are covered by a single category.

The stress categories are similar to those in the ASME Code which is why the same designations were chosen as shown in Fig. 2, Allowable Stresses for the MC. In addition, the reference value in Fig. 2 for the general

primary membrane stress (P_m) and for the reference stress range for the sum of primary and secondary stresses (e.g. $P_L + Q$) may be 370 N/mm^2 at a maximum at room temperature and 320 N/mm^2 at a maximum at design temperature.

2 Structural Analysis Procedure

The phases of the structural analysis are given in Fig. 3. Owing to correlation with the construction of the plant and the licencing procedure the structural analysis can be subdivided into three phases:

1. Calculations and verifications to be performed prior to commencement of construction work.
2. Calculations and verifications to be performed in the course of construction.
3. Final evaluation after pressure test.

3 Examples of Structural Analyses

The structural analyses for the MC are exemplified by the earthquake and nozzle analyses.

3.1 Earthquake Analysis

In the course of earthquake analysis evidence of the structural stability and leaktightness of the MC is provided.

The overall dynamic analysis for the undisturbed clamped shell leads to overall stress and stability analyses (Ref. /2/) to ensure structural stability. Horizontal, vertical and rocking spectra together with the damping values applicable for the load condition concerned are used as a basis. In Fig. 4 typical spectra are compared with the relevant natural vibration mode.

If for a particular load condition leaktightness of the MC is required then local analyses must be carried out in addition to the overall analyses. In this case a check is first made to determine whether a decoupled analysis of the locks can be carried out. In the event of interaction of the vibrations of the locks and the MC the analysis of the locks is carried out in conjunction with that of the containment.

3.2 Analysis of Nozzles

The analysis procedure for nozzles comprises a series of consecutive steps, as shown in Fig. 5. The third step covers the actual detailed stress analysis (Ref. /3/), the mutual influence of nozzles and proof of the acceptability of the specified differential temperatures.

As the analyses are made on the basis of ideal geometric configurations although in practice deviations are unavoidable, the strain measurements on selected nozzles during the pressure test are particularly important. After completion of all pipe system calculations a comparison of the calculated nozzle loads with the allowable loads is carried out by means of interaction analysis as part of the final evaluation of the MC.

References

/1/ Sicherheitstechnische Regel des Kerntechnischen Ausschusses "KTA 3401.2, Reaktorsicherheitsbehälter aus Stahl, Teil: Auslegung, Konstruktion und Berechnung", BUNDESANZEIGER 188a (8. Oktober 1980).

/2/ ANDERSEN, A., BANTLE, S., HABIP, L.M., "Stability Analysis of Spherical Metal Containment Vessels".
Lecture presented at the 5th SMiRT Conference, J 6/6

/3/ ANDERSEN, A., BANTLE, S., "Optimization of Containment Nozzles"
Lecture presented at the 5th SMiRT Conference, J 6/8

Load condition (state of plant)	
Design	DF
Erection	MF
Normal	NB
Upset	AB
Test	PF
Faulted	ST

Loads (impact on MC)
Dead load
Pressures
Temperatures
Loads upon internal and external structures
Live loads
Wind loads
Snow loads
External events

Service limit category
0
1
2
3

Fig. 1 LOAD CONDITIONS, LOADS AND SERVICE LIMIT CATEGORIES FOR THE CONTAINMENT (MC)

stress category / service limit category	P_m	P_L, $P_m + P_b$ $P_L + P_b$	+Q	+F
0	0.67	0.75[1)]		
1	0.67	0.75	1.67	+
2	0.75	0.84	1.84	(+)
3	0.84	0.94		

The reference value is the yield strength or the elastic limit ($R_{po,2T}$).

[1)] Instead of primary stress calculation the application of simplified design rules is permissible

Fig. 2 ALLOWABLE STRESSES FOR THE MC

Fig. 3 STRUCTURAL ANALYSES OF THE MC

[1] May be necessary in the individual case

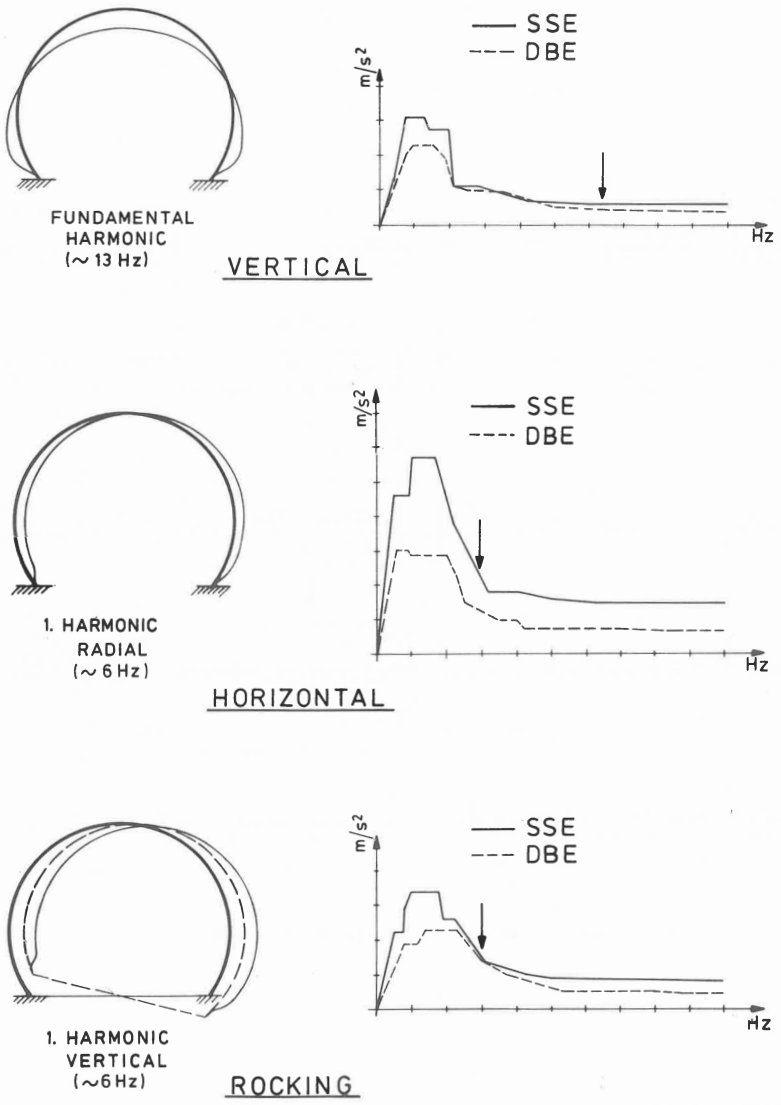

Fig. 4 NATURAL MODES AND RESPONSE SPECTRA FOR EARTHQUAKE ANALYSIS

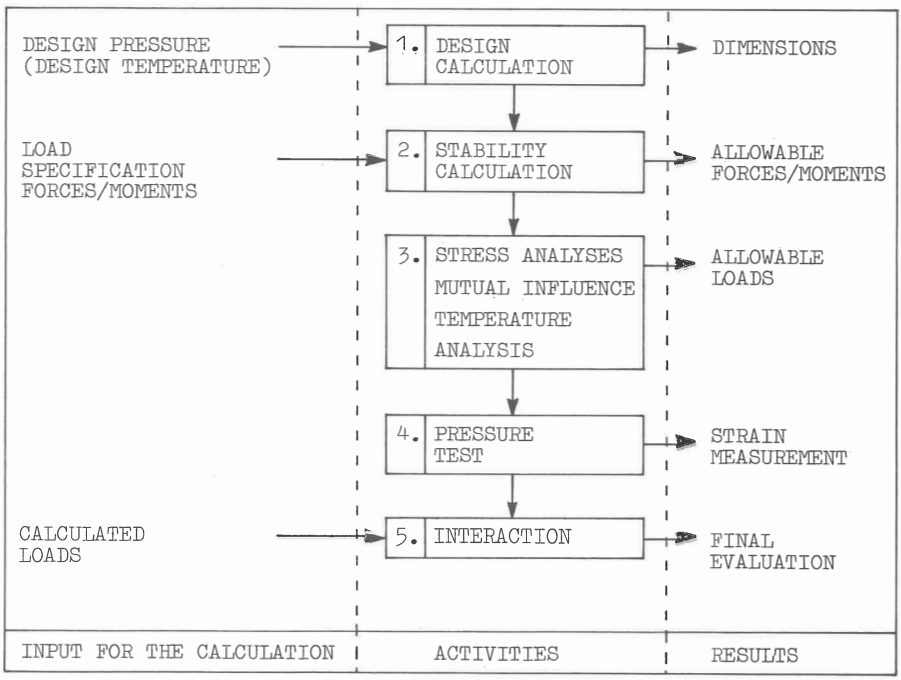

Fig. 5 STRUCTURAL ANALYSES OF NOZZLES