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Division IX

STRATEGIES FOR DISMANTLING OF THE SAFETY CONTAINMENT

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ABSTRACT

In this paper strategies, working procedures and structural design verifications for dismantling of the safety containment, consisting of the sealing skin, the pressure shell and the splinter protection concrete, are presented. The paper deals with the task of dismantling, the geometry of the containment, the materials used in construction, the various operating conditions and the dismantling procedure. The basis for different operating conditions is the advance planning with the dismantling company in order to carry out a detailed assessment of the dismantling conditions. This advance planning prevents unnecessary iterations in order to ensure a smooth dismantling process.

INTRODUCTION

The plant described here is currently dismantling the reactor containment. One major step in the decommissioning phase of NPPs is the dismantling of the reactor containment.

The first intervention in the supporting structure of the safety containment is the creation of new openings, which become necessary for the dismantling of inside components e.g. pipelines, condensation pipes, etc. or as additional escape routes.

For the different deconstruction states, Woelfel Engineering verifies the stability of the load-bearing components in the various deconstruction steps of the pressure shell and the splinter protection concrete also including the load case earthquake.

The content of the investigation is the verification of the sufficient stability of the construction states that occur during dismantling of the splinter protection concrete, the pressure shell and the sealing skin.

For the dismantling of the safety containment, the available informations from the as-built documents are summarized and transferred into three individual 3D FE shell models for the sealing skin, the pressure shell and the splinter protection concrete. Using these 3D FE shell models, the separate deconstruction sections are investigated according to the deconstruction sequence.

GEOMETRIE

Splinter protection concrete / solid construction

The geometry of the load-bearing structure is taken from the as-built drawings.

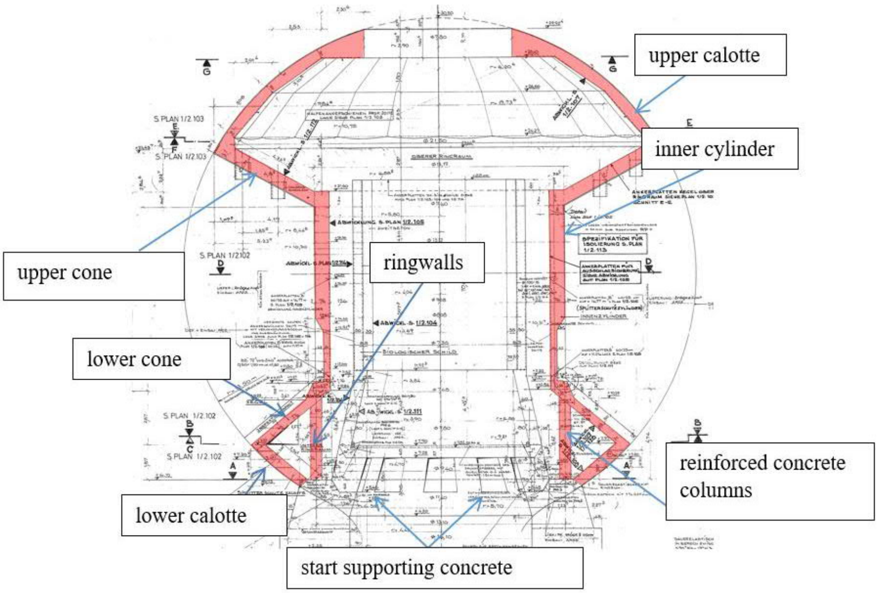


Figure 1: Sectional drawing of the splinter protection concrete

Steel structure / pressure shell

The geometry of the steel structure of the pressure shell is taken from the as-built drawings. The main components of the pressure shell are explained in the drawing shown below.

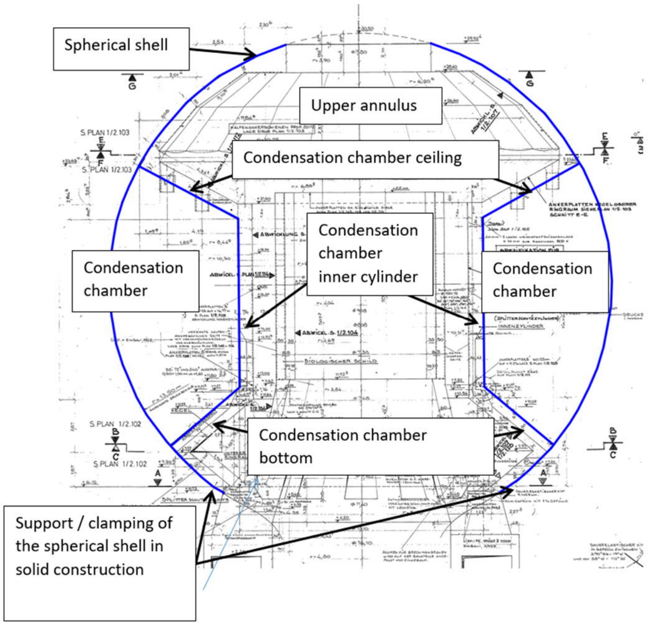


Figure 2: Sectional drawing of the splinter protection concrete

Sealing skin

In the available documents, the essential data on the sealing skin can be found in the as-built drawings and the associated existing structural analysis for the sealing skin.

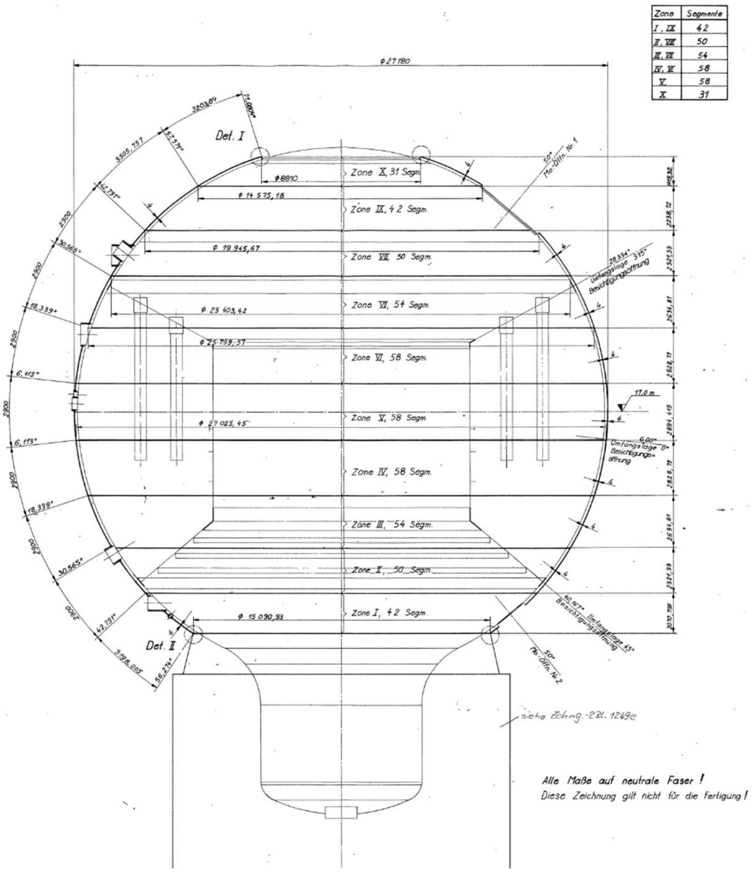


Figure 3: Sectional drawing of the sealing skin

DECONSTRUCTION SEQUENCE

The principle dismantling sequence is shown below. The deconstruction description and the corresponding plans of the executing company form the basis for the verifications. The entire support structure is divided into ten dismantling sections. In the respective deconstruction sections, explicit deconstruction states are captured in a 3D FE Shell model for analyzing stability and structural safety.

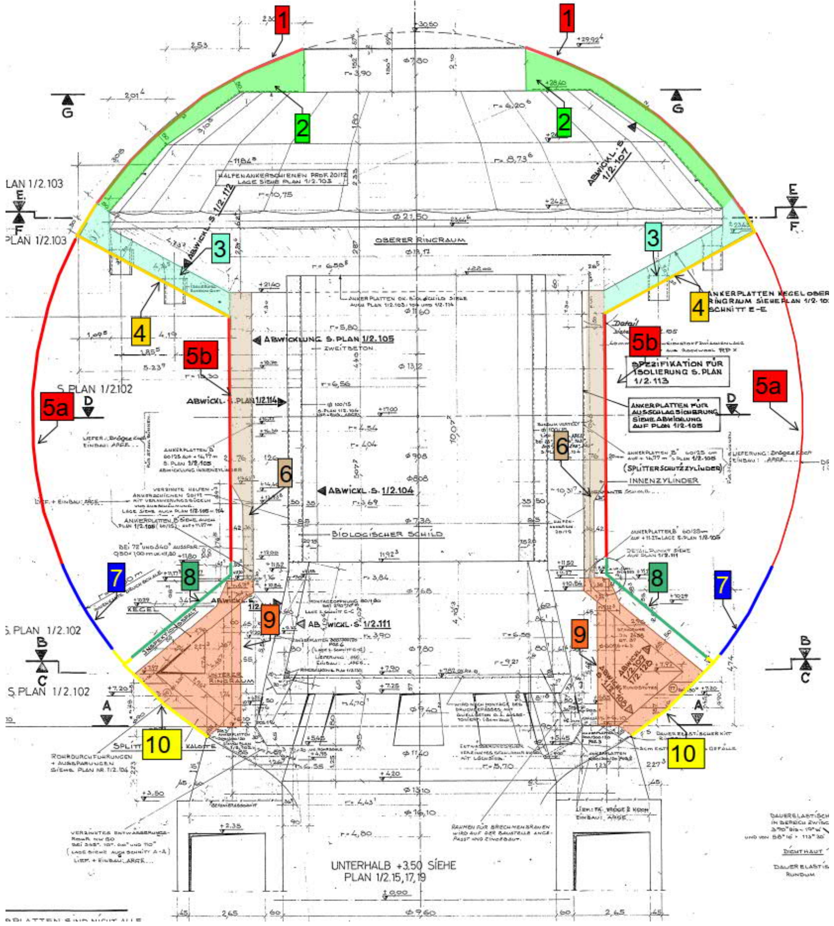


Figure 4: Sectional drawing with the dismantling sections

Principle procedure in dismantling

The demolition, as performed in sections 1 to 10, is executed circumferentially and symmetrically for each section to ensure minimum eccentricity. Two opposite demolition segments are cut and dismantled at the same time. This principle is applied to the entire deconstruction of all deconstruction sections.

Approximately 4400 pressure equalization pipes (asbestos pipes) with a diameter of 32 to 50 mm are embedded in the complete existing concrete support structure. These pressure equalization pipes are removed by core drilling with a diameter of 100 mm before dismantling the individual segment.

The dismantling of the upper annular ceiling (dismantling section 1 and 2) is realized with the help of a temporary auxiliary construction mounted on the upper cone. The necessary equipment and the required staff are located on the temporary auxiliary construction and carry out the work overhead.

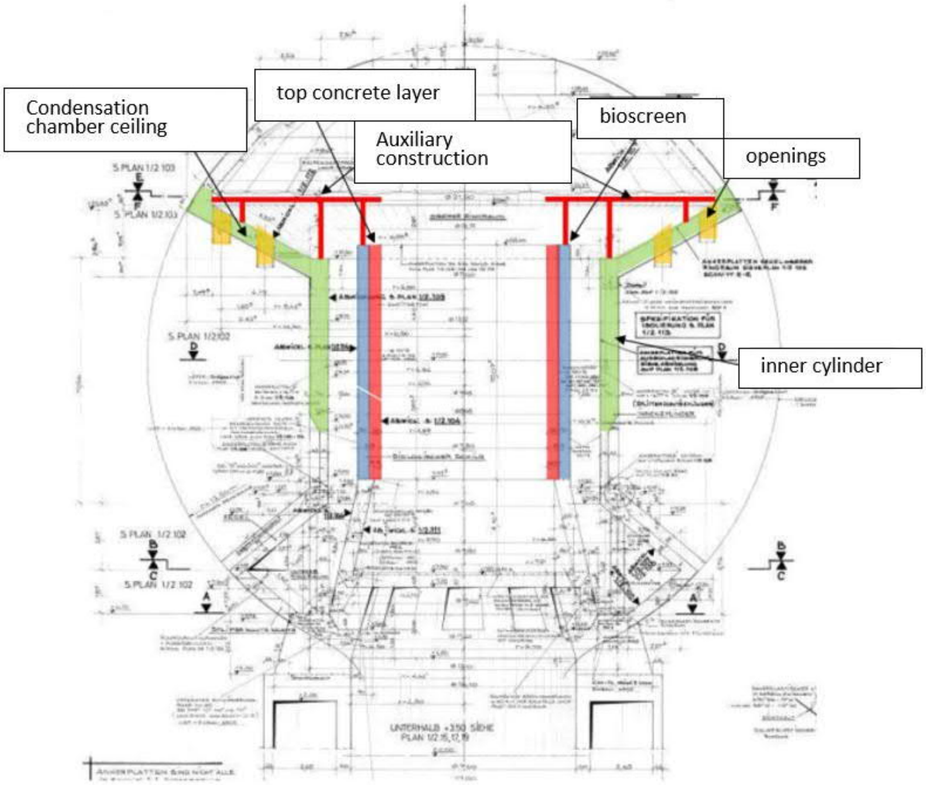


Figure 5: Temporary auxiliary structure for the dismantling of the ceiling upper annular space

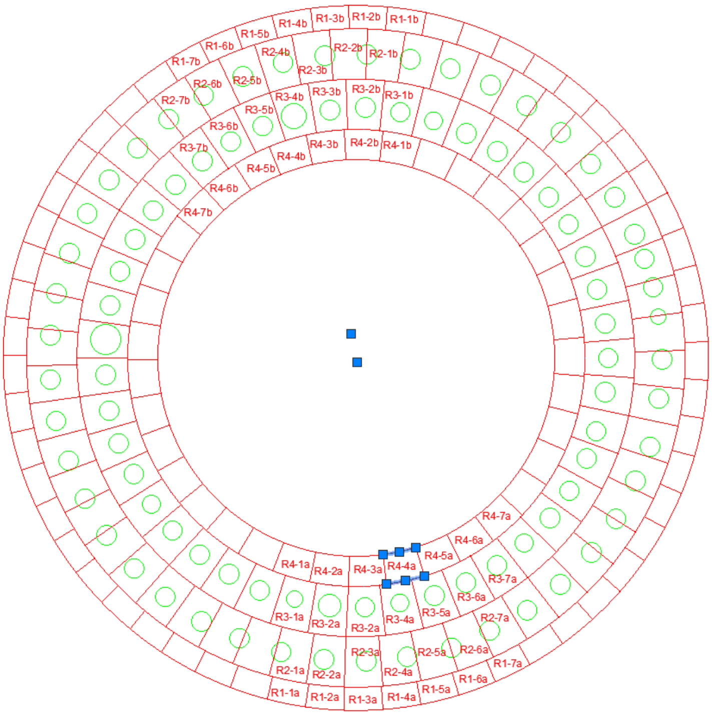


Figure 6: Exemplary overview of the dismantling segments in dismantling section 3

Before working on dismantling sections 3 and 4, the temporary auxiliary construction must be removed. Afterwards, the approx. 1400 pressure equalization pipes existing in the dismantling section 3 can be over drilled as described. These core drillings partly serve as guides for push-through anchors in order to fasten the single segments of the pressure shell (dismantling section 4) to the concrete of the upper cone and therefore, securing the single parts of the pressure shell (dismantling section 4) against falling. This procedure can be executed without complete scaffolding of the condensation chamber and allows simultaneous deconstruction of dismantling sections 3 and 4.

The single segments of the dismantling sections 3 to 10 are moved to the established disposal routes with the aid of an additionally mounted overhead auxiliary crane. This crane is shown in figure 7.

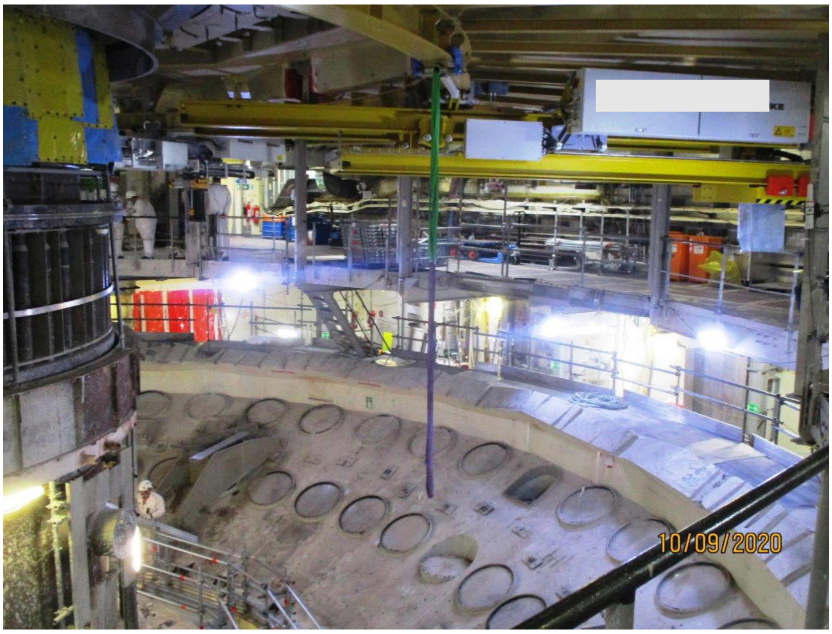


Figure 7: View of the condensation chamber ceiling; ceiling of upper annulus already removed, (source: courtesy of operator)

CALCULATION

Basics

Based on the as-built documents, three 3D FE shell models of the individual structures are created. The individual structures are the sealing skin, the pressure shell and the reinforced splinter protection concrete.

The reinforced concrete structure is calculated on the basis of DIN EN 1992-1-1. According to the guideline of the Federal Ministry of Transport, Building and Urban Affairs, the concrete quality of the as-built documents, B450, is assigned to an actual concrete quality C30/37 in the FE calculation model. The reinforcing steel considered in the calculation is uniformly assumed to have a yield strength and tensile strength of 400 N/mm². In areas where the prestressing steel St135/150 is used instead of the reinforcing steel BSt III, the calculated required reinforcement is subsequently multiplied by the factor:

$$f_{y,k,BstIII} / f_{y,k,St135/150} = 400/810 = 0{,}49 \tag{1}$$

Alternatively, the calculated reinforcement can be compared with the effective value of the prestressing steel reinforcement

$$A_{s,eff} = A_{s,St135/150} \text{ x } 810 / 400 = 2{,}03 \text{ x } A_{s,St135/150} \tag{2}$$

The material characteristics of the sealing skin are determined according to DIN EN 1993-1-1: Material yield strength: $f_{y,k} = 330$ N/mm²; Partial safety factor $\gamma_M = 1.1$ (conservative approach)

$$f_{y,d} = 330/1.1 = 300 \text{ N/mm}^2 \tag{3}$$

Since all calculations are performed at global safety level, the partial safety factor of the load side is assigned to the design stress. Conservatively, this is assumed to be $\gamma_F = 1.5$

$$f_{y,d,M+F} = 300 / 1.5 = 200 \text{ N/mm}^2 \tag{4}$$

The design stress is thus below the permissible stresses for diaphragm stresses specified during construction.

The welds are cross-section butt welds. Analogous to the as-built structural analysis and in accordance with the specifications of DIN EN 1993-1-8, the "weld factor" is set at 1.0 (i.e. same strength as the base material).

The partial safety factor of the load side can be set to $\gamma_{F,\, AE}$=1.0 according to DIN EN 1991-1 for the design situation "earthquake", deviating from the permanent / temporary design situation. The design stress for the earthquake thus results in

$$f_{y,d,M+F} = f_{y,d} / \gamma_{F,AE} = 300 / 1{,}0 = 300 \text{ N/mm}^2 \tag{5}$$

The material characteristics of the pressure shell are determined as St 37-2; Yield strength $f_{y,k} = 235$ N/mm².

Verification of the stability of the structur in the individual deconstruction steps

As the explanation of the total dismantling sections is very extensive, we will briefly explain the dismantling sections 3 in the following paragraphs.

The deconstruction section 4 (pressure shell) is secured to the condensation chamber ceiling with anchors. The steel of the condensation chamber ceiling (deconstruction section 4) has a weight per unit area of 280 kg/m². This weight per unit area is conservatively taken into account in the FE model with 300 kg/m² (3.0 kN/m²).

A live load of 2.0 kN/m² is assumed on the condensation chamber ceiling. For deconstruction section 3, the segments (1st row), which are cut during the deconstruction work, are not depicted explicitly in the FE-model. A substitute load $q_{segment}$ plus a substitute moment $m_{segment}$ from the partial segment is considered as shown in Figure 8.

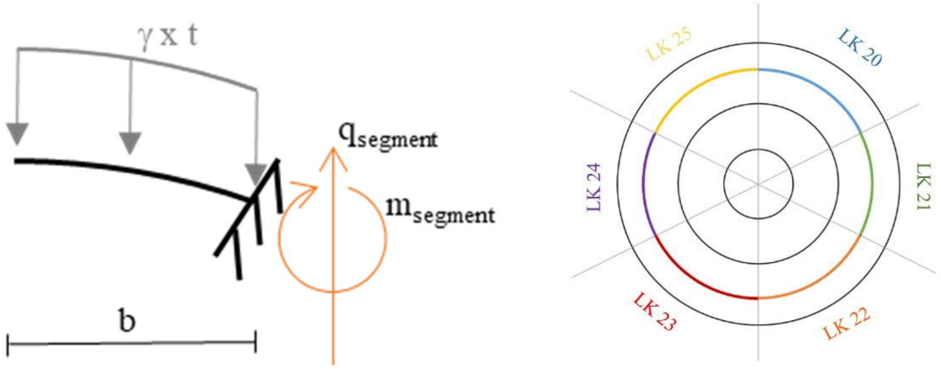


Figure 8: Model of the load approach deconstruction single segment plus the associated load schemes

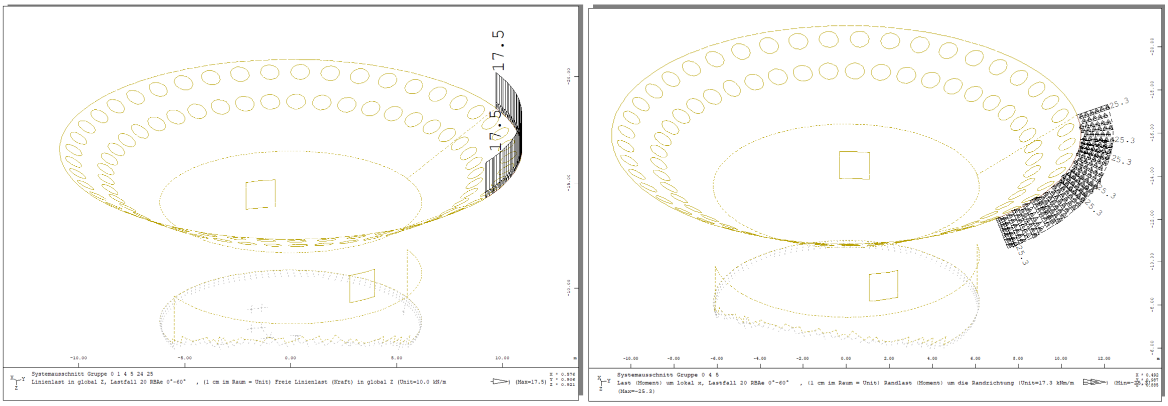


Figure 9: Exemplary load case 20 of substitute load $q_{segment}$ and substitute moment $m_{segment}$

As described above, the reinforced concrete structure is examined in the individual dismantling sections and the associated intermediate dismantling steps, and the utilization of the existing reinforced concrete reinforcement is calculated. Here, the existing load-bearing structure is checked in terms of its degree of utilization, with reference to the current standards. The results are compared with the existing planning documents (reinforcement plans) and the load-bearing reserves are determined.

The deconstruction of the pressure shell and the sealing skin are described in the different deconstruction states and the ultimate limit state of the calculated deconstruction states and their degree of utilization are described in detail.

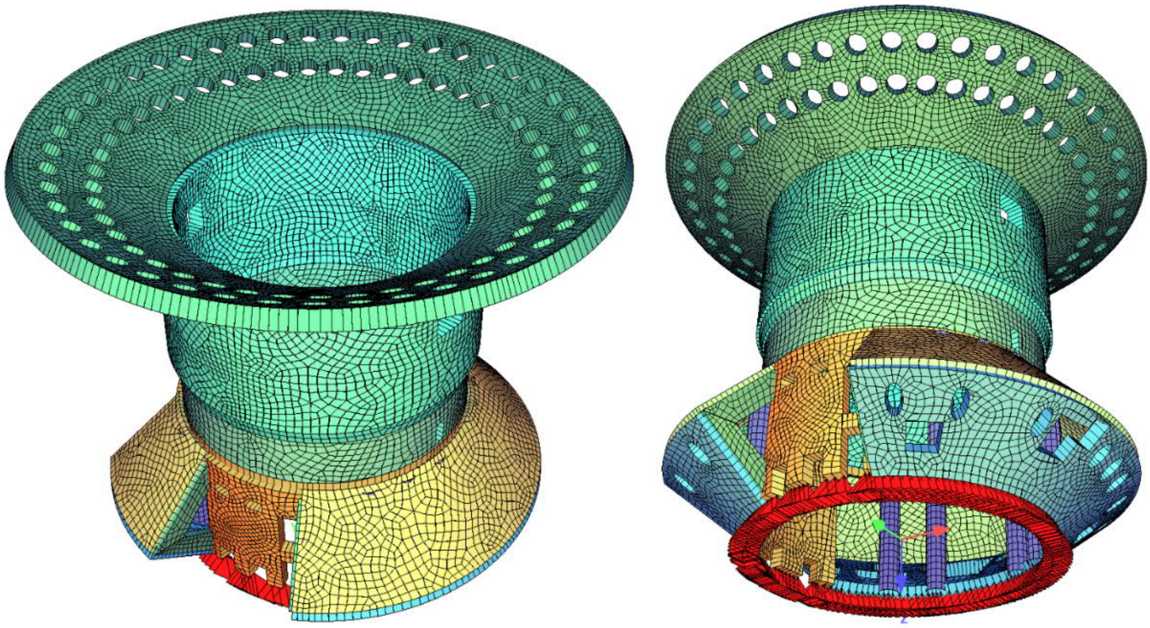
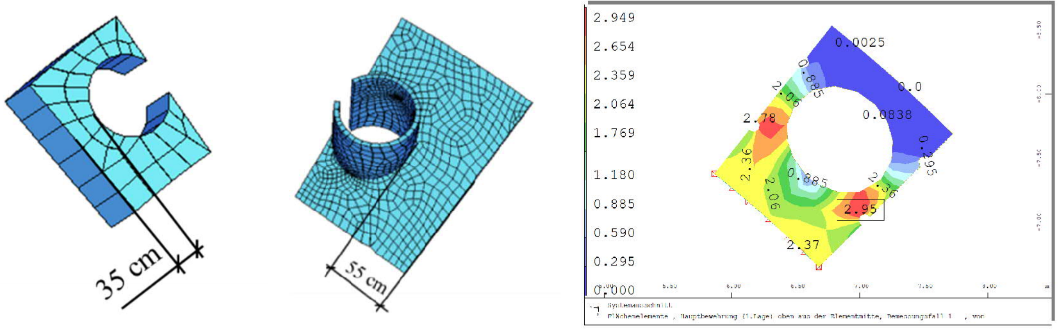


Figure 10: 3D finite elements concrete model with complete deconstructed ceiling of the upper annulus (Deconstruction section 1 and 2 completed)


Deconstruction concrete component

Deconstruction Steel condensation chamber ceiling

Calculated reinforcement content of a deconstruction element with breakthrough and core drilling of the asbestos pipes

Figure 11: 3D concrete- and Steelmodel with calculated reinforcement content of a deconstruction element

Earthquakes according to DIN 4149 and DIN EN 1998-1

Normative basis for the design of structures in German seismic zones are the standards DIN 4149 (introduced by the building authorities since 2005), DIN EN 1998-1 and the KTA regulations 2201.1 to 2201.4. After consultation with the operator, only the requirements of DIN 4149 and DIN EN 1998-1 are taken into account due to the given hazard potential during dismantling. The site is located in earthquake zone 1 according to the current map of earthquake zones and geological subsoil classes of the Ministry of Interior of the Federal State concerned. The site is classified in subsoil class S (areas of deep basin structures with thick sediment fill) according to the earthquake zone map for Germany. According to DIN 4149 and DIN EN 1998-1, components are to be classified into corresponding importance categories according to their significance for the protection of the general public or the consequences associated with the collapse. After consultation with the operator, only the protection of people located in the structure is defined as a design objective for the deconstruction states. Accordingly, a classification into significance category II (ordinary structures) is justified. The resulting significance coefficient is $\gamma_{\text{I, significance category}} = 1.0$.

Both DIN 4149 and DIN EN 1998-1 define the scope of application of the respective standard as the design, dimensioning and construction of buildings and civil engineering structures. The design values of ground acceleration in these standards are based on a probability of occurrence or exceedance of 10% within 50 years. The reference period of 50 years thus corresponds to the design life for "buildings and other ordinary structures" defined in DIN EN 1990, Table 2.1. The time for the deconstruction states to be evaluated in this report is significantly lower and is conservatively estimated at 10 years in agreement with the operator. According to DIN EN 1998-1, this results in a significance coefficient of $\gamma_{\text{I, Pn}}$=10%=0.6 for this period and an exceedance probability of 10%.

The resulting design spectra according to DIN 4149 or DIN EN 1998-1 taking into account the above-mentioned boundary conditions are derived in a separate design. Conservatively, a behaviour coefficient of q = 1.0 (elastic behaviour) is used.

The maximum equivalent accelerations/forces based on the peak values of the spectra and a weight factor of $\Gamma = 1.5$ are obtained as:

for horizontal seismic action:

$$a_{\text{Replacement}} = 0{,}45 \text{ x } 1{,}5 = 0{,}68 \text{ m/s}^2 \text{ resp. } \quad Fi = 0{,}45 \text{ x } 1{,}5 \text{ x } m_i = 0{,}68 \text{ m/s}^2 \text{ x } m_i \qquad (6)$$

for vertical earthquake action:

$a_{Replacement}$ = 0,36 x 1,5 = 0,54 m/s² resp.   Fi = 0,36 x 1,5 x m_i = 0,54 m/s² x m_i (7)

As the auxiliary structures in the deconstruction state are used exclusively as working platforms (no storage areas), the design value of the actions due to earthquakes is based on only 1/3 of the permissible live load of the respective auxiliary structure (only quasi-permanent portion; $\psi_2 = 0.3$). The same applies to the governing action combination.

These determinations for the seismic design are implemented in a separate 3D FE shell model to determine the utilization levels of the support structure elements and to be able to specify or define the influence on the deconstruction sections.

CONCLUSION

The complex structure of the safety containment is used as an example to illustrate the problems involved in planning and executing the dismantling. The verification of the structural safety of the containment in the various dismantling stages must be planned in detail in advance and verified in detail by calculation including the load case earthquake.

REFERENZEN

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DIN EN 1993-1-1, *Eurocode 3: Design of steel structures - Part 1-1: General design rules and rules for building construction;* German version EN 1993-1-1:2005 + AC:2009 in conjunction with NAD

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DIN EN 1998-1, *Eurocode 8: Design of structures for earthquake resistance - Part 1: Basic principles, seismic actions and rules for buildings;* German version EN 1998-1:2004 + AC:2009, Issued: 2010-12

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