Realistic Finite-Element Model for the Core-Support Structures of a KWU-PWR 1300 MW; Check of the Design Analyses; Superelement Technique

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Within the scope of the licensing procedure of the "Konvoi"-project in West-Germany TÜV-Bavaria was authorized to check the design analysis of the Core-Support-Structures (CSS). We understand by "Konvoi"-project the simultaneous construction and licensing of three Pressurized-Water-Reactors (PWR) with 1300 MW in three different federal states of Germany.

The CSS is an extremly complex structure of a steel construction. The CSS had to support and to protect such filigreed components like fuel bundles or control rods. Only small deviations of the dimensions are permissible. In the past slight irregularities like a broadening of a gap at the core shroud caused fuel rods to fail. Unexpected thermal displacements resulted in a fracture of fuel assembly alignment pins. In addition to the stresses the thermal displacements must be calculated. The complex interaction of pressure, temperature, flow induced forces and radiation effects had to be taken into account.

The design analysis was carried out according to the ASME-Code /1/ and to the corresponding German code KTA 3204 /2/ respectively.

In the past the design analysis of the CSS was done by conventional methods. Programs for beams, plates and shells were used. The CSS was separated into isolated parts and was analysed by simplified methods. The interaction of the CSS and fuel elements under combined loadings such as pressure, temperature, mechanical loads and pre-deformations could only be determined approximately.

In connection with the "Konvoi"-project "Siemens-KWU" developed a detailed three-dimensional finite-element-model for the CSS. The design analysis of the CSS was carried out with this model. TÜV-Bavaria decided to check this analysis by a calculation of similar quality.

Three-dimensional Finite-Element-Model
Superelement-Technique

The finite-element-programm ANSYS /3/, was used on the computer system DEC-VAX 750.

The CSS was constructed as a three-dimensional finite-element-model, and made as realistic as possible. Beam-, plate-, shell- and volume-elements were used.

As a simplification a symmetry of the CSS and the loads was assumed relative to an eigth-sector.

Some details of the construction and some loads are incompatible with the symmetry requirements. But they could be treated as irrelevant and could be analysed

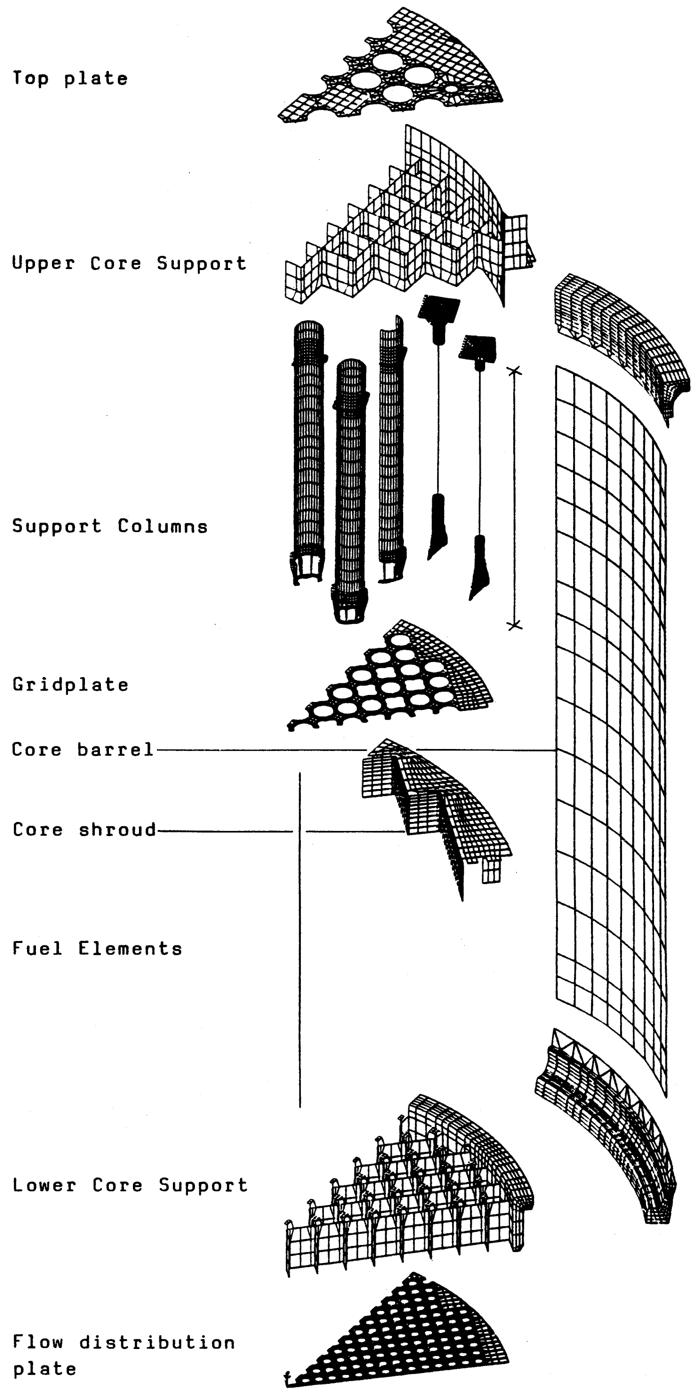

Figure 1: Explosion plot of Core-Support-Structure

by separate researches respectively. F. i. the openings in the core barrel have been disregarded. Recent investigations have shown, that the reinforcement of the openings compensate the loss of stiffness caused by the missing material.

A development was achieved during the generation process of the lower core-support-structure. Starting with three-dimensional volume elements and ending in plate elements with different thickness we could show that the latter model was sufficient for our purposes.

The isolated structures of the CSS were modelled through finite-element-models (Figure 1). These separate models can be used as superelements. Load vectors were generated which made it possible to apply the loadings like weight, pressure, temperature also in a spatially distributed type.

The superelements can be used like any other elements.

Using the superelement-technique the superelements can be joined together to the overall-model. Through that the number of the unknowns is reduced to a minimum by the limitation of the master degrees of freedom.

In our model the superelements are generated by 10000 elements and they have 18000 nodes. The overall-model is generated by 22000 elements and 36000 nodes and we have only about 900 master degrees of freedom.

At the so-called master degrees of freedom additional loads can be applied. The superelements which f. i. model the support columns of the upper core structure, the grid plate and the lower core support can be used separately for detailed investigations.

Why did we develop our own finite-element-model? -
The best independent check of an extensive numerical computation is to do one's own computation. In this way one discovers the problems and learns the limits of the method. The comparison of the results can be done on a qualitatively comparable level. We wanted to improve our knowledge of the interaction of the components inside the reactor.

Comparison with the presented results

The displacements, reactions and stresses under conservative loadings were determined for the upper core support, the lower core support and the upper core structure composed of its superelements. In order to generate condensed models for dynamic analysis the natural frequencies were calculated and compared with the presented data /4, 5/ (Table).

Nat. Freq.	KWU	TÜV
LCS	85.5	81.0
LCS w. FDP	78.9	75.2
UCS	80.0	79.1
UCS w. TPL	70.1	68.7
UCSC	44.5	45.2

Table

The overall-model was used to examine five different in-service load cases.

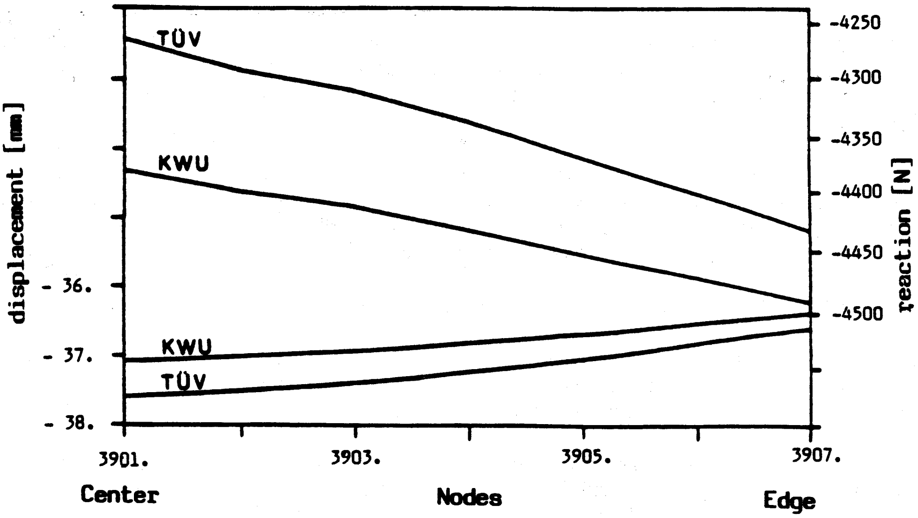

Figure 2: Lower-core-support, Comparison of results

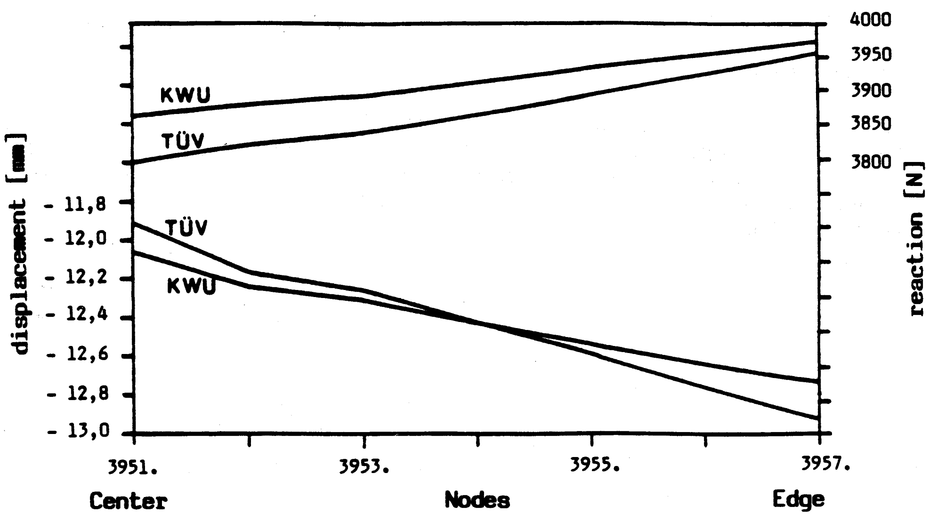

Figure 3: Grid plate, Comparison of results

These conservative load cases resulted in the relevant stress intensity ranges for the fatigue analysis. As an example of the results the displacements and reactions at the lower core support (LCS) (figure 2) and the grid plate (figure 3) for an extreme load case are shown. The results are plotted from the center to the edge of the core. The absolute values and the tendency match with the presented data. These displacements and reactions occur in positions where fuel assemblies are situated. These data are important for the loadings of the fuel assemblies and are an example of interaction between CSS and core.

The spatial distribution of reactions and displacements at the nodes where the fuel bundles are connected to the grid plate are shown in figure 4.

Conclusions

With the overall-model of the CSS one can analyse the elastic interaction of the connected structures including the fuel elements under complex load combinations.

The applied loads are - weight, flow induced forces, temperature effects, thermal gradients, pressure differences (constant and distributed), mechanical forces, pre-deformations and restraints. Each generated load can be multiplied by a factor and can be superimposed.

Simplifications in our model are: no core shroud in the overall-model, no gap-elements at the connection nodes of the different flanges, increased application of plate elements instead of volume elements. These simplifications caused no significant effect on the results.

The comparison showed that our model is satisfactory for the check of the design analysis, and is a suitable basis for analysis which will be necessary in the future.

The superelement-technique is extremly flexible. Modifications can be carried out on single superelements, load vectors, connection nodes and on the overall-model.

Because of the similar construction of the CSS in the previous generations of PWR's the presented model can be used with small changes as a basis for follow-up analysis.

References

/1/ ASME-Code, Section III, Division 1, Subsection NG
Core Support Structures

/2/ KTA 3204 - Reaktordruckbehältereinbauten
Fassung 3/84

/3/ ANSYS Users Manual, Swanson Analysis Systems Inc.,
Houston Johnson Road

/4/ KONVOI-Strukturanalyse der RDB-Einbauten
Siemens AG, UB KWU, U9 114

/5/ KONVOI-Analyse des mechanischen Verhaltens
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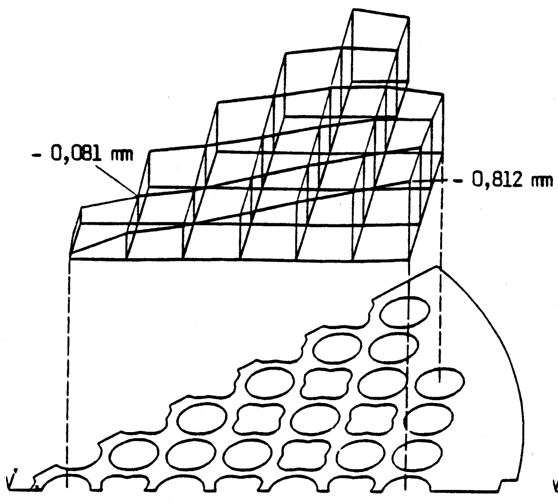
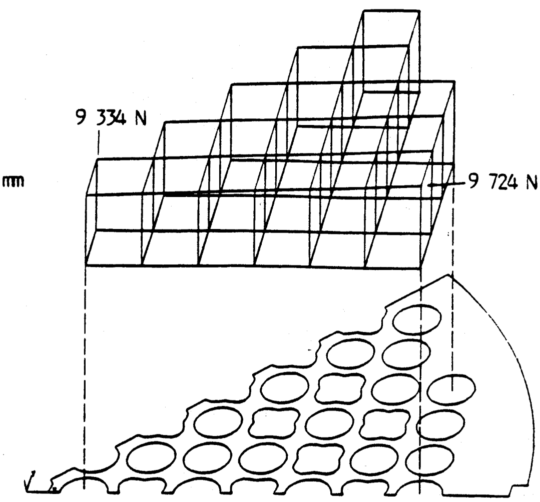
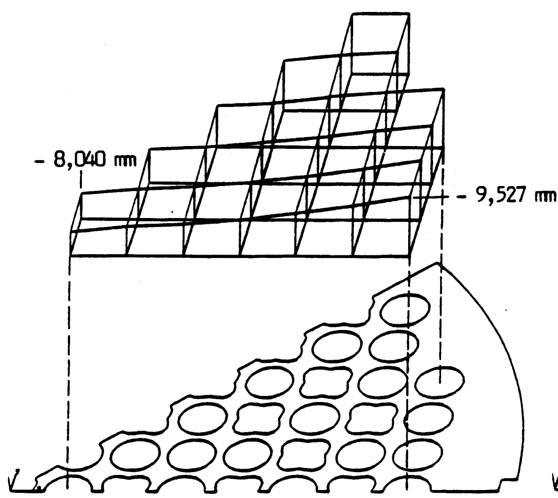
TÜV Bayern, G2-EGD



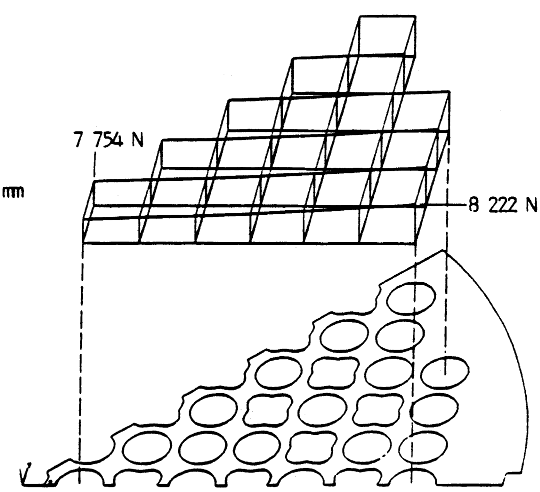
Displacements Load Case 4



Reactions Load Case 4



Displacements Load Case 8



Reactions Load Case 8

Figure 4: Gridplate - displacements and reactions