A Nonlinear 3D Containment Analysis for Airplane Impact

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Abstract

In the Federal Republic of Germany, it is pertinent safety philosophy to design nuclear facilities against airplane impact, despite its very unlikely probability of occurrence. For safety reasons, the following conditions have to be met:

1) In the close impact area of the projectile, the structure can be stressed up to its ultimate load capacity, so that impact energy is dissipated partly. Hereby, it must be strictly clarified that local structural failure within the impact zone is avoided.
2) Residual impact energy is transferred to the "non-disturbed" containment structure and to the interior structure.

The subject of reinforced concrete structures under impact loads shows still clear gaps between the findings of experimental and analytical analyses. To clarify this highly nonlinear phenomena comprehensive tests have recently been performed in Germany. It is the aim of this paper to carry out a three-dimensional analysis of a nuclear facility.

To perform the calculation, the finite element ADINA code is applied. In order to obtain optimum results, a very fine mesh leading to several thousand DOF is used. To model the impact area of the concrete structure realistically, its linear and mostly nonlinear material behaviour as well as its failure criteria must be taken into account. Herewith the structural response is reduced due to increased energy dissipation. This reduction rate is valued by variation of the assumed size of impact zone, the load impact location and the assumed load-time function.

Furthermore, the containment wall thickness as well as the rate of reinforcement shall be varied on condition that local wall failure is excluded. The final evaluation is given as floor-response-spectra for discrete points. It is the definite aim of these evaluations to compare the different results of containment behaviour between a simplified model and one that is based on sophisticated data including nonlinear (also experimentally determined) properties and a relatively fine three-dimensional discretization.

1. Introduction

In the Federal Republic of Germany, it is pertinent safety philosophy to design nuclear facilities against airplane impact, despite its very unlikely probability of occurence. The subject of concrete structures under impact loads shows still clear gaps between the coordination of experimental and analytical studies which is demonstrated by the state-of-the art report [1,2]. In order to clarify the highly nonlinear problems for the concrete structure, comprehensive tests have recently been performed. For the design two aspects have to be considered:

1) In the close impact area of the projectile the structure is strengthened up to its ultimate load bearing capacity. Hereby, it must be strictly classified that local structural failure is avoided. Material nonlinearities, however, are locally confined to the impact area.

2) Residual impact energy is transferred to the non-disturbed containment structure and to the interior structure so that an interaction between structure and reactor components can be observed. The floor response due to airplane impact is of decisive interest with regard to reactor component design. Thus, structural dynamics are of global character.

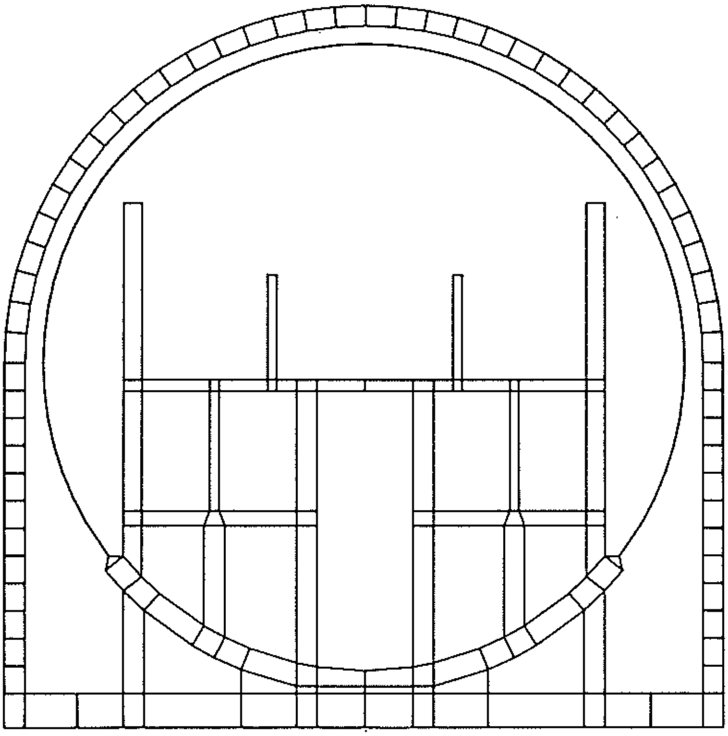


Fig. 1: Overview of the general system

2. General system behaviour

In this paper the attempt is made to solve the above two aspects of design in a more appropriate manner. To perform the calculations, the finite element method is used by applying a modified version of the ADINA[3] code. Fig. 1 shows an example for a three-dimensional system discretization of a typical nuclear facility using VOLUME elements. In order to obtain optimum results a fine mesh leading to several thousand DDF is required so that in particular the influence of higher frequencies can be taken into account. To model the impact area of the concrete structure realistically, its linear and mostly nonlinear material properties and corresponding failure criteria must be respected. Because of structural symmetry only half of the system is discretized by introducing appropriate boundary conditions.

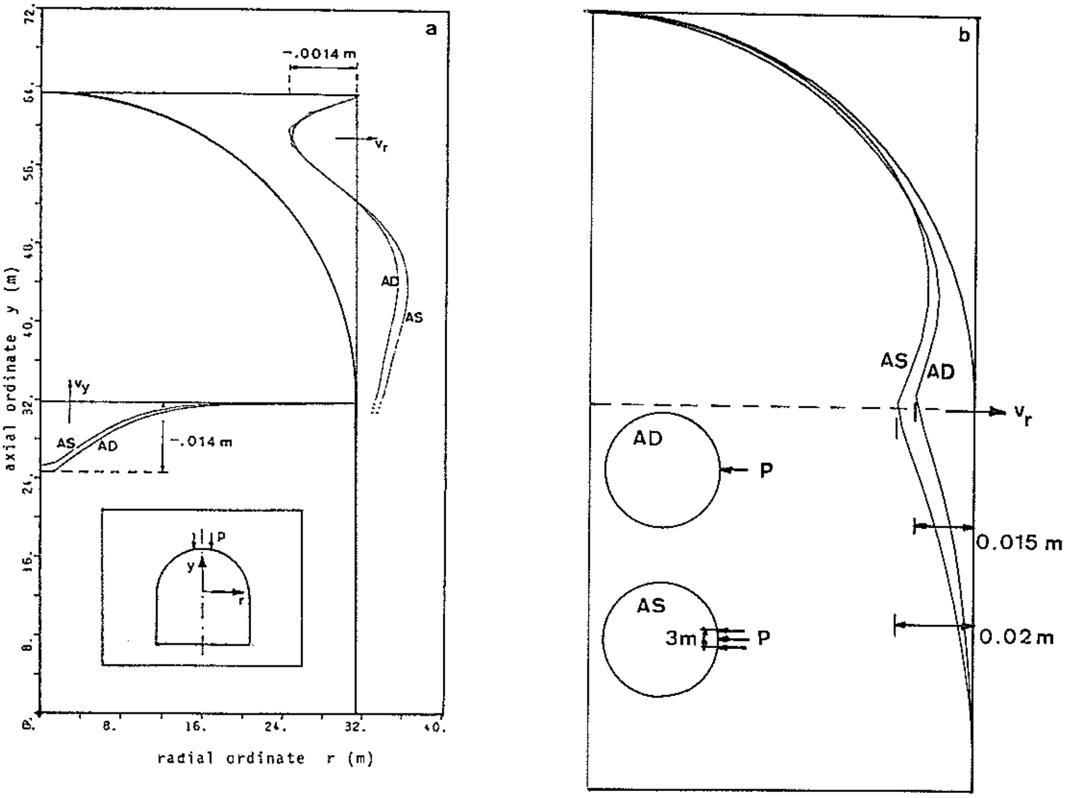


Fig. 2: Statical pre-estimations (AD=ADINA, AS=ASHSD)

a) Vertical load *b) Horizontal load*

3. Preliminary investigations

Since nonlinear three-dimensional analyses require a comprehensive computational effort, preliminary investigations are firstly carried out for adjustment of the program code to be applied. These investigations concentrate both on statical and dynamical considerations.

3.1 Statical considerations

Nonlinear behaviour is locally confined to the impact zone which is assessed by application of statical investigations. Containment displacement functions due to concentrated loads are evaluated both by the ADINA and the ASHSD [4] code, linear material behaviour assumed. These preliminary studies are performed for the containment only, using a discretization according to fig. 1. The comparison with the symmetric vertical load case for 110 MN (s. fig. 2 a) shows good agreement for both codes and with the asymmetric load case for 110 MN (s. fig. 2 b) as well. These load deflection curves permit a satisfactory judgement of the nonlinear influence area.

3.2 Dynamical considerations

The comparison of results between ADINA and ASHSD serves to evaluate the discretization mesh concerning the frequency response. This way, it has to be proven that the eigenvalues of the model cover the frequency content of the load function. Further, the response history should be consistent, i.e. the history must be independent of discretization fineness.

For the clamped containment the fundamental frequencies are evaluated by

ASHSD : 5.2 Hz (first harmonic), 9.3 Hz (second harmonic), 11.0 Hz (zero harmonic, vertical) and by

ADINA : 5.4 Hz (first harmonic combined with small overlay from the third harmonic), 11.1 Hz (second harmonic), 11.6 Hz (zero harmonic, vertical).

4. Modelling

4.1 System modelling

Fig. 3 a shows an example of the overall 3D system model with regard to axisymmetric behaviour. The basic mesh consists of VOLUME elements belonging to a linear element group. The soil supporting the facility is discretized by frequency independent lumped parameters attached to the foundation mat. According to the a.-m. pre-estimations the impact zone is demonstrated by the hatched area (s. fig. 3 a) where material nonlinearity must be taken into account. This area supplementally superimposed to the basic discretization is highly fine-meshed, partly through multi-layered nonlinear VOLUME elements (s. fig. 3 b), partly through nonlinear TRUSS elements representing the (considerable) longitudinal and transversal mild steel reinforcement (not shown in fig. 3 b). This fine mesh, however, can only represent a more integral stress-strain behaviour; decisive for the quality of this mesh is its con-

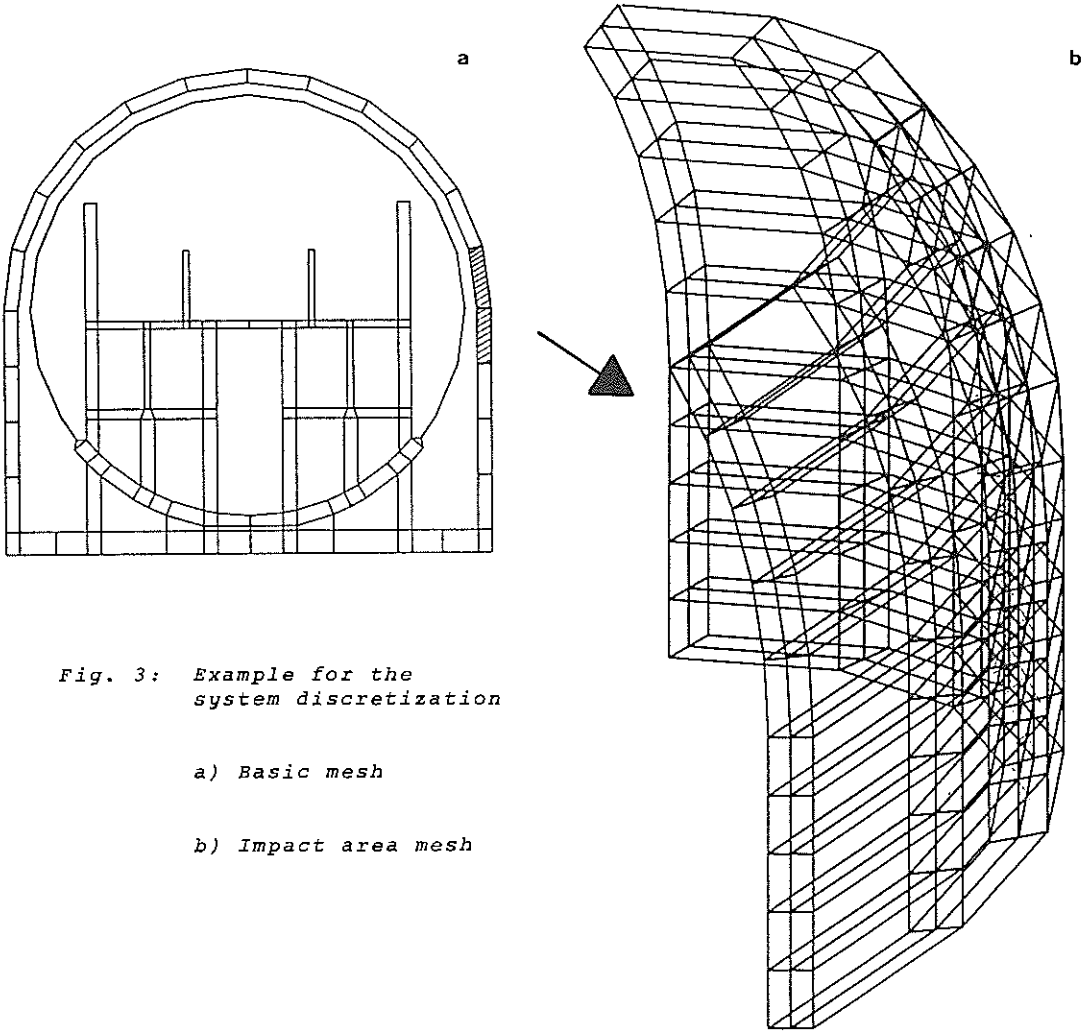


Fig. 3: Example for the system discretization

a) Basic mesh

b) Impact area mesh

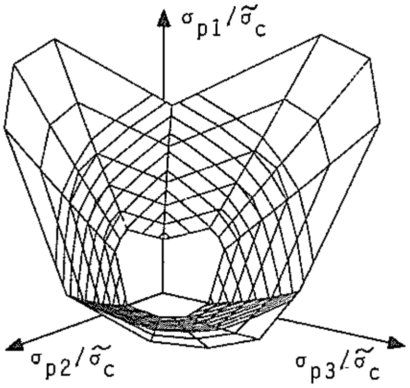


Fig. 4:

Concrete model input

formity with the structural component behaviour.

4.2 Material modelling

The steel behaviour seems rather reliably explored [1] with regard to strain-rate-effects. These experimentally determined data are introduced to the TRUSS elements in the impact zone.

A much more complicated material behaviour is given for the concrete. Uniaxial experimental results from strain-rate-effect.measurements are transformed to a three-dimensional behaviour assuming affinity with common static 3D results since corresponding 3D data are still outstanding [1]. For the impact area nonlinear three-dimensional behaviour is defined under successive isotropic assumptions with eventual unloading. The failure surface is characterized through a polyhedral mesh with additional compaction failure criteria. An example to check the input model is shown in fig. 4.

5. Loading conditions

The aircraft impact load function to be used in the calculations according to German licensing is shown in fig. 5 a. It is uniformly distributed over an impact area of 28.26 m^2 (radius 3.0 m). This load function is defined conservative. Conservatism implies linear behaviour of the structural system, too. Consequently an analysis of a nonlinear structural system is not consistent when using the same function (as for linear system) instead of reducing it. However, results due to this procedure are conservative, as nonlinearity is utilized for the reduction of the structural response only, but not for the load function. For the first calculations it is assumed that a horizontal load is applied to the transition point from cylinder to sphere.

The frequency content of the load function can be seen in fig. 5 b. The spectrum amplitude corresponds to an acceleration history which is identical to the load history in fig. 5 a, having a maximum value of 110 cm/s^2. The spectrum shows the maximum content in the range between 5 Hz and 150 Hz.

6. Parametric discussion

The initial input parameters are:

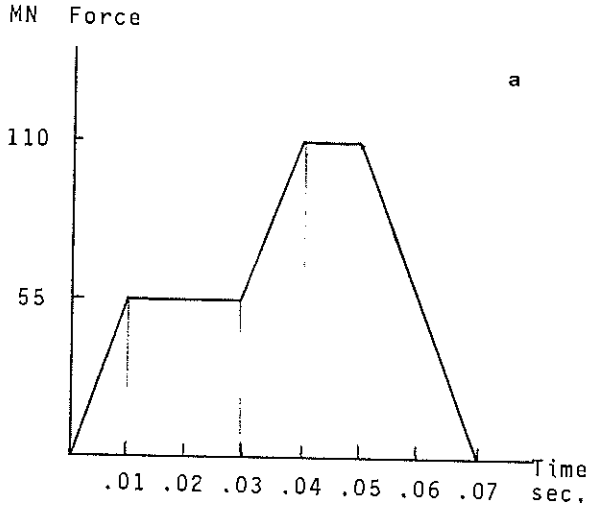
containment:	max. height	60.4 m
	max. diameter	62.8 m
	containment wall thickness	1.8 m
	concrete quality	8 25
impact area:	mild steel quality	8St 1080/1320 longitudinal 8St 420/500 transversal
soil:	shear modulus	$G = 300\ MN/m^2$

The parametric modifications intentionally to be performed are:

size of impact zone
load impact location
load-time function
containment wall thickness
amount of reinforcement

7. Conclusive remarks

It is the definite aim of these evaluations to compare the different results of the containment behaviour between a simplified model and one that is based on sophisticated data including nonlinear (also experimentally determined) material properties in conjunction with a relatively fine three-dimensional discretization. The investigations are still current at this time period.



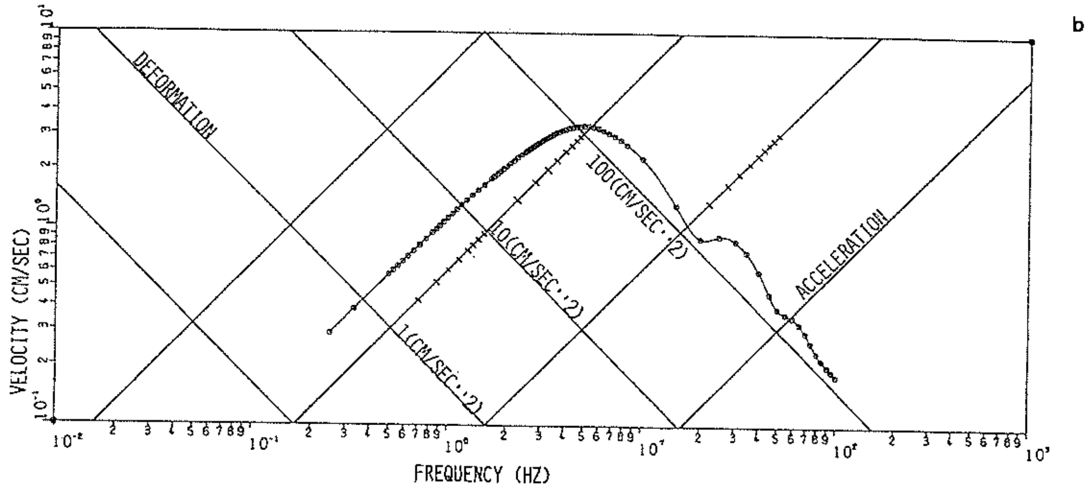


Fig. 5: Loading conditions

a) Load function

b) Frequency content

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