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Conditional Probability of Failure from Impact Loads of the Reactor Shield Shell

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ABSTRACT: The aim of this analysis is to determine the conditional probability of failure of the reactor shield shell, WWER 440 type, from impact loads. The impact loads may be caused by falling of the roof structure. The analysis is performed with the computer code SOLVIA, taking into account the nonlinear behaviour of the materials during the impact excitation. The amplitude of loading changes in steps in order to assess the ultimate capacity of the structure. The process of occurring and spreading of the cracks in the concrete shell is illustrated at different moments of time. The performed nonlinear analysis to impact excitation gives grounds to make conclusions concerning damages in the reinforced concrete shell and a process of plastification of material of the steel shell. The conditional probability of failure is defined with the assumption of log-normal distribution of the capacity and of the loading.

1. DESCRIPTION OF THE CIVIL STRUCTURE

This investigation is a part of seismic PSA performed for units 3/4 in Kozloduy NPP, Bulgaria. The main building of Unit 3/4 comprises the turbine hall, the longitudinal electric shelves building, the reactor building, the ventilation centre and the transversal electric shelves building. The reactor building has dimensions in plan 39 m / 126 m. The reactor compartment is up to level +10.50 m, built of cast-in-place reinforced concrete (walls and floor structures). The main bearing structure of the high part of the reactor building is a frame comprised of monolithic reinforced columns and steel roof trusses. The columns of that part of the structure are supported on the walls of the reactor compartment at level 10.50 m. The steel trusses are 39 m long and are hinge supported to the columns. Over the roof trusses lie heavy roof reinforced concrete panels. The walls of the high part of the reactor building are of reinforced concrete.

2. MODELLING

The aim of this analysis is to determine the conditional probability of failure of the reactor shield shell from impact loads. A general view of the shield shell can be seen in Fig.1. From

geometrical point of view the shell can be considered composed of two parts - low cylindrical one (from level +11.8 m to level +14.3 m) and upper spherical one (from level +14.3 m going up to level +17.825 m). Both of them consist of inner region, made of steel 5 cm thick, and outer reinforced concrete region 10 cm thick. The structure is symmetric to the vertical axis passing through the centre of the dome. This makes it possible to build up a finite element model for performing an axisymmetrical analysis - Fig.2. The finite elements used in the model are quadrilateral with 8 nodes (3 nodes on each side). Each region of the shell (the steel one and the RC one) of both parts of the shell, the low and upper one, are made of two rows of finite elements. In Fig.3 is illustrated the finite element mesh of the upper part of the axisymmetric model in the vicinity of the vertical axis of symmetry.

3. FALLING OF REACTOR BUILDING ROOF

The roof could fail under the condition that shear failure occurs in the columns or the anchor bolts fastening the roof trusses to the columns are broken. Another possible scenario of failure of the reactor building roof is when the bending moments in transverse direction of the columns exceed the load-carrying capacity in bending. The most probable failure is assumed to be the shear failure of the anchor bolts fastening the roof trusses to the columns. The roof failure can produce an impact loading on the reactor dome.

4. DESCPRITION OF THE IMPACT LOADING

Main feature of the impact load is its extremely short duration – usually not more than 100E-3 s. The function of loading used in this analysis is presented in Fig.4. This curve is a standard one [1] and is used to describe the impact of falling plane. The duration of the excitation is 70 ms (milliseconds) and is scaled to 1. In this way the characteristics of the loading are defined. The amplitude of the loading is defined on the basis of the balance between the kinetic and the strain energy. For the impact loads it is essential the magnitude of the deformations in both bodies. In this case, it is assumed that the deformations of the body that receives the impact (the shield shell) are very small compared to those of the body that falls on it. The factors that influence the magnitude of the impact are the weight and the deformations of the body that falls and the velocity at the moment of the impact. The analysis is carried out with the following values of the parameters:

- the mean value of the weight of the body that falls is 300 kN and the coefficient of variation is 0.5;
- the mean value of the velocity at the moment of the impact is 12 m/s and the coefficient of variation is 0.25;
- the mean value of the deformation of the body that falls is 1m and the coefficient of variation is 0.5.

With these assumptions the mean value of the magnitude of the impact is 4468 kN and the coefficient of variation is 0.44.

Usually the impact excitation is applied as uniformly distributed loading on some area. In this case as a concervative assessment of the area of interaction is assumed a circle with 0.368 m radius at the central portion of the dome of the shell - Fig.5 .

The analysis is performed with the computer code SOLVIA [2], taking into account the nonlinear behaviour of the materials during the impact excitation. The model of the concrete in the SOLVIA computer code is known as Otossen model. It is based on nonlinear relationship between the stresses and deformations in the concrete and on criteria for cracking

and failure in tension when the tensile strength is reached and crushing when the compressive strength of the concrete is reached. The steel is elasto-plastic material with yield limit of 485 MPa. A certain conservatism is assumed in the modeling of the shield shell as a result of the fact that the axisymmetrical model does not account the available reinforcement of the RC shell.

5. RESULTS AND EVALUATION

The amplitude of loading changes in steps in order to assess the ultimate capacity of the structure. When the amplitude of the impact reaches the value of 20000 kN a process of plastification of the steel shell starts. In Fig.6 the process of occurring and spreading of the cracks in the concrete shell is illustrated at different moments of time (the loading function is plotted in Fig.4). Time is measured in milliseconds. In Fig.7 can be seen the distribution of the effective (von Mises) stresses at different moments of time. The stresses are measured in MPa. In Fig.8 is presented the deformed scheme, the maximum displacement of the centre of the dome in vertical direction is 0.03 m. This value complies with the preliminary assumption for small deformations of the shield shell.

The performed nonlinear analysis to impact excitation gives grounds to make the following conclusion. For values of the magnitude of the impact about 20000 kN considerable damages in the reinforced concrete shell are observed. These damages are crushing of the concrete in the region just under and round the place where the loading is applied, and intensive cracking of the neighbour region with approximate length that equals two times the length of the loaded region - Fig.6. The values of the effective stresses in the steel increase with the increasing of the loading and reach maximum values of about 590 MPa which means that a process of plastification of the material of the steel shell starts. With increasing of the magnitude of the impact the zone of plastification increases and that could cause total failure of the shield shell. For the assessment of the capacity the following safety factors are assumed:

1. Fs = 1.2 - factor that accounts for the difference between the yield stress and the ultimate stress;
2. Fm = 1.2 - factor that accounts the conservatism of modelling;
3. Fa = 1.1 - factor that accounts for the conservatism in the applying of the loading.

In this way the mean value of the capacity is determined to be 31680 kN.

The coefficient of variation of the capacity is defined conservatively as 0.283 (the model uncertanty and the random uncertanty are assumed 20%).

The conditional probability of failure is defined with the assumption of log-normal distribution of the capacity and of the loading. The value of the conditional probability is calculated as 6.137E-3.

6. CONCLUSION

An efficient approach for assessment of the conditional probability of failure from falling of roof structure over reactor shield shell is suggested in this study. The main idea used in this approach is that falling of the roof is considered like impact load with extremely short duration. Nonlinear analysis in time domain gives the possibility to assess the response and capacity of the structure. This approach could be applied in other similar tasks like falling of cranes or other heavy equipment when PSA analyses are done.

REFERENCES

1. RSK-Leitlinien fur Druckwasserreaktoren, LL DWR 10.81.
2. SOLVIA - Users Manual for stress analysis, SOLVIA Engineering AB.

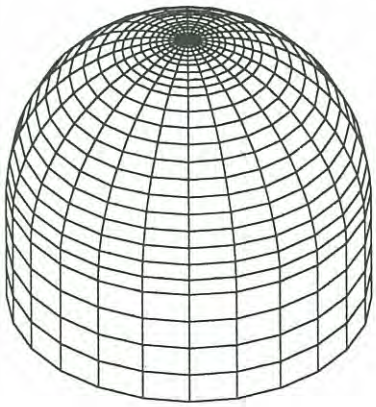

Fig.1 General view of the shield shell

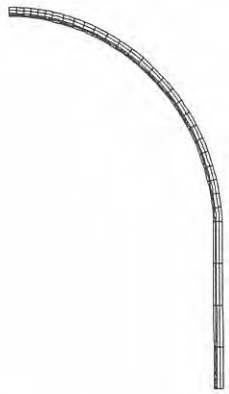

Fig.2 Axisymmetrical model

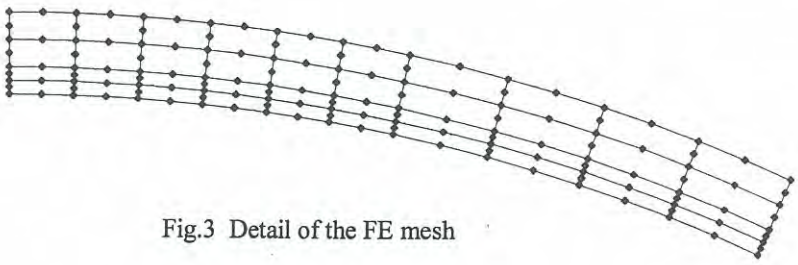

Fig.3 Detail of the FE mesh

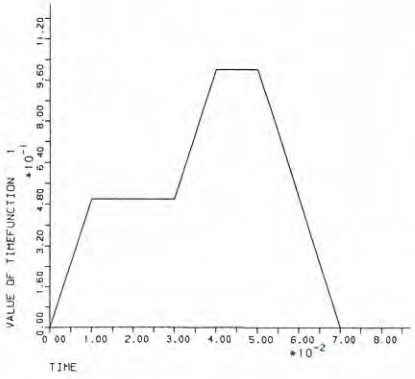

Fig.4 Loading function

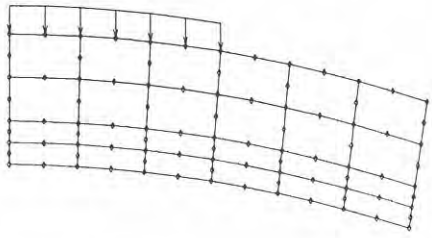

Fig.5 Loading distribution

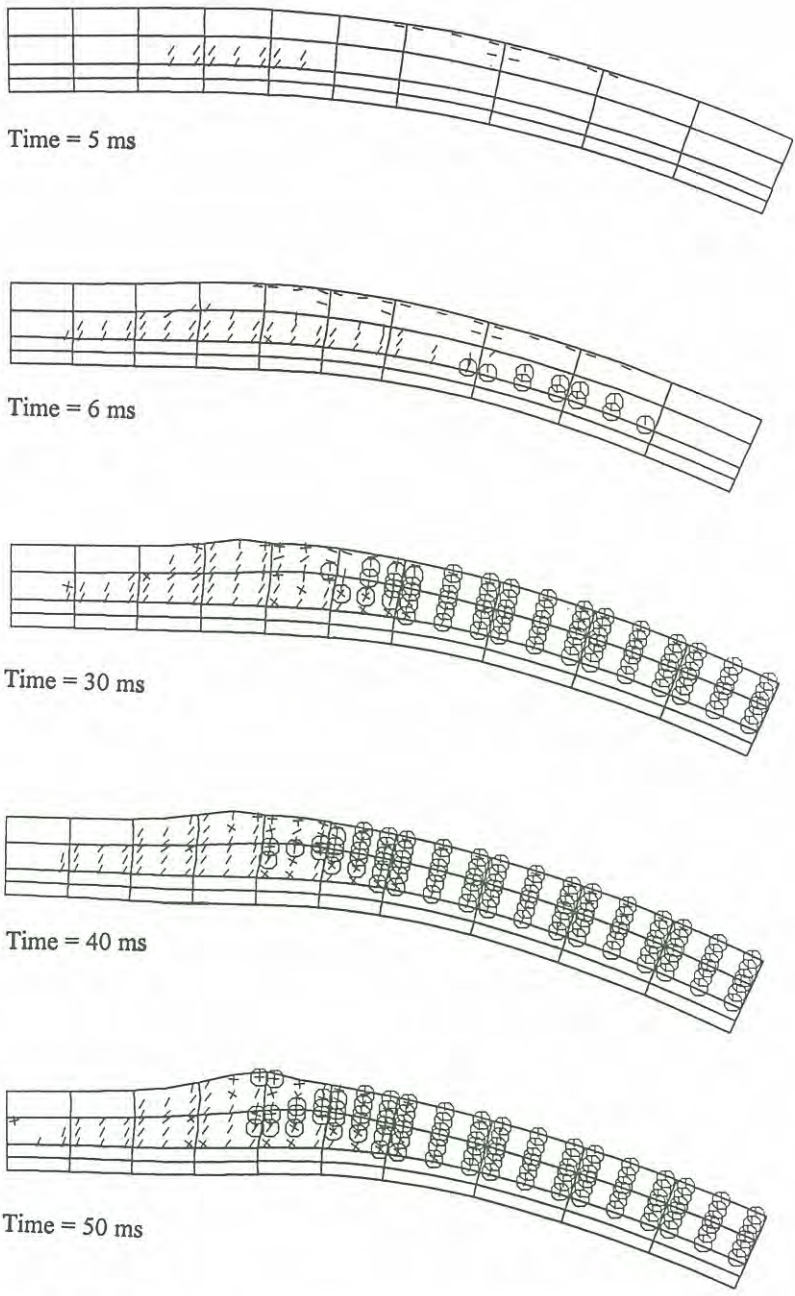

Fig.6 Distribution of the normals to cracks at the different moments of time

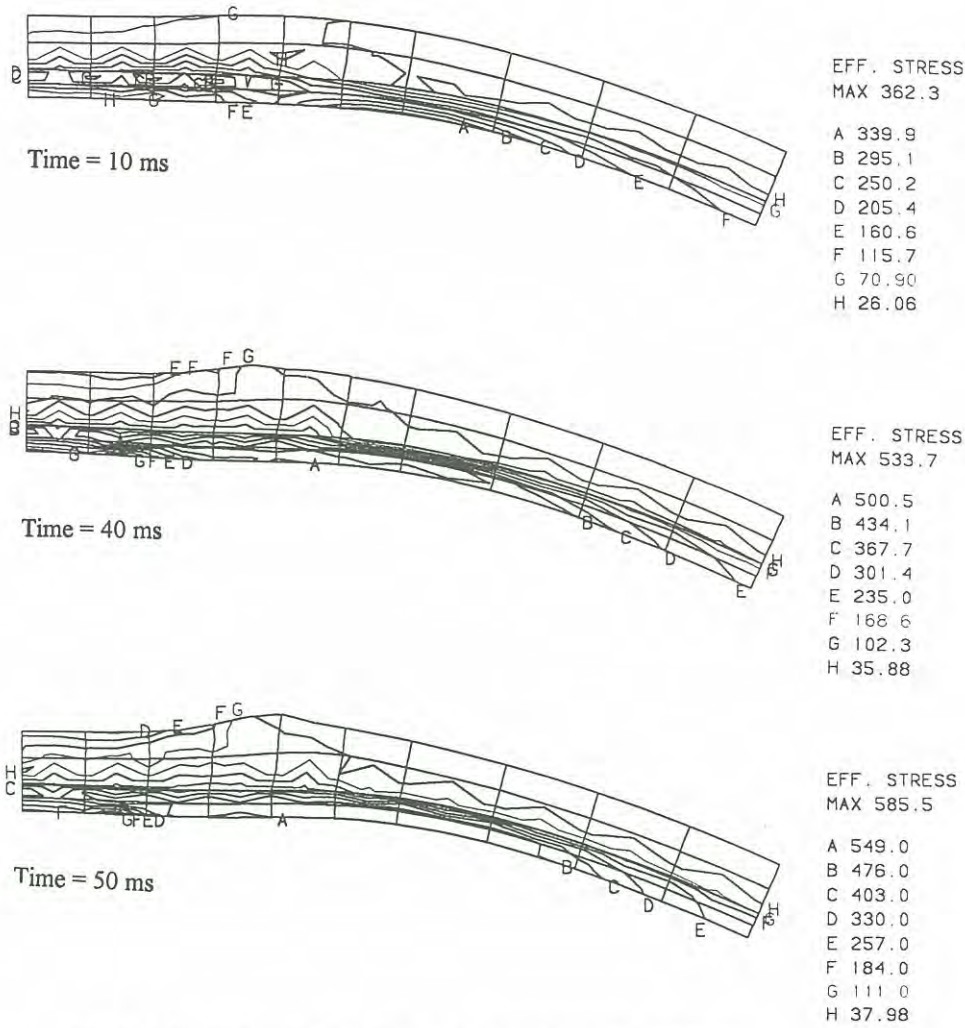

Fig.7 Effective stress distribution at different moments of time

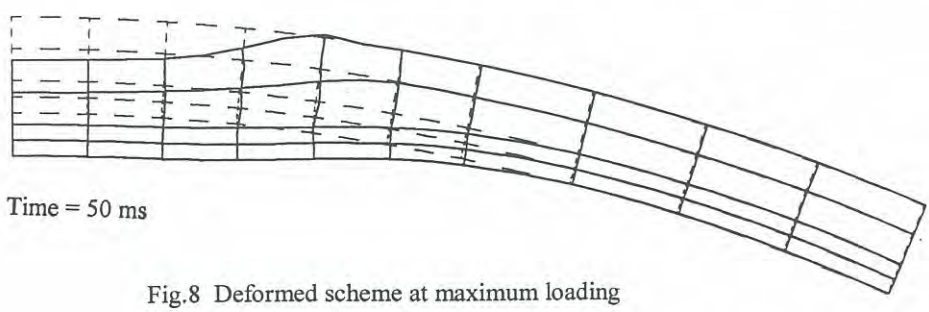

Fig.8 Deformed scheme at maximum loading