Transactions of the **14th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 14), Lyon, France, August 17-22, 1997

HW/2

Testing of a concrete containment model coated with a composite liner

Danisch R.(1), Hansen H.(2), Liersch G.(3), Peter U.(4)
(1) Siemens AG, Germany
(2) Hochtief AG, Germany
(3) Bayernwerk AG, Germany
(4) RWE Energie AG, Germany

ABSTRACT

At the test facility of the civil construction company Hochtief in Walldorf, near Frankfurt/Germany investigations with a reinforced concrete containment model coated with a composite liner are jointly being performed by Siemens and Hochtief.

This research is to be seen in the frame work of the different activities for the containment design of the European Pressurized Water Reactor (EPR). It is supported by the group of German utilities involved in the Basic Design of the EPR.

1 INTRODUCTION

Within the EPR Basic Design a composite liner, as proposed by the German partners at the beginning of the cooperation, is jointly being qualified by EDF and Siemens to provide leak tightness during normal operation as well as in case of severe accidents. If its feasibility is confirmed the composite liner can be used to increase the beyond design leak tightness of the prestressed containment chosen for the EPR or as an alternative to a metallic liner for containments with less prestressing or without prestressing. This alternative is being investigated by the tests at Walldorf.

2 OBJECTIVES OF THE TESTS AT WALLDORF

The Walldorf tests will extend the experience with composite liner materials gained up to now by the qualification program and by tests alredy performed at the university of Karlsruhe [1].

Additional pretests with coated beam elements had been performed at Walldorf during spring 1996, the results of which will be used to ensure the success of the reinforced containment model to be tested during spring 1997. The findings of the pretests will be reported in chapter 3.2.

With the containment model the feasibility of composite liner materials in combination with reinforced concrete will be demonstrated. The main items investigated concern the structural behaviour of the model, the implementation criteria of composite liners and their capability to bridge small and large cracks. In addition the influence of steel fibre concrete as compared to normal concrete will be studied.

2.1 Structural Behaviour

Concerning its structural behaviour the containment model is used to study the capability of available analytical tools for containment design to predict:

- the load bearing capacity of the model up to its failure
- the deformations in the elastic and non-linear range
- the cracking behaviour at the cylindrical shell and especially at the transition between the basemat and the cylinder as well as at the areas around openings

The theoretical values will be compared with measured ones during testing.

2.2 Liner Aspects

Based on the pretests four different liner systems had been selected for the coating of the inner surface of the containment model. The liner systems are based on vinyl esther for the resin and glass fibre fabrics for reinforcement. They differ with respect to the details of the application, the layers and the fabrics applied.

Concerning the composite liner the model is used:

- to gain experience with the implementation conditions of the composite liner
- to study the performance and capability of a composite liner to bridge small and large cracks at the concrete surface up to the rupture of the model and to check its behaviour at edges
- to investigate the interaction between the composite liner and steel at the junction to penetrations
- to check the possibility to locally repair the liner

2.3 Cracking Behaviour of the Concrete

The objective of the containment model is to produce cracks at the concrete surface supporting the liner which are representative of those of a real reinforced concrete containment. The concrete quality and the reinforcement has been selected accordingly.

In order to induce crack widths much larger than at a real containment wall, in certain areas cracking plates consisting of plastic material will be installed and the reinforcing bars will be covered with rubber sleeves. The objective is to study the behaviour of the composite liner under extreme conditions and to check its ultimate limit to provide leak tightness. Therefore at these artificially weakened areas there will be a high concentration of strain gauges.

A limited part of the model is poured with steel fibre concrete in order to study its capability to reduce cracks and to increase ductility which may have a beneficial effect on the liner performance.

3 PRE-TESTS

3.1 Objectives and Description

A series of pre-tests had been performed with the following objectives:

- to test the performance of the measurement devices to be applied to the containment model
- to study the failure mechanism of the composite liner and the concrete
- to study a method to create larger single cracks by special treatment of reinforcement in order to check ultimate performance of the liner
- to define stress strain curves for the combined system consisting of composite liner and the reinforced concrete. These curves will be used for the non-linear calculations of the containment model

Two different types of tests had been performed:

In a first series reinforced concrete beams coated with different liner systems had been bent. The test arrangement is show in figure 1.

Rather different failure modes had been observed. Some coating failed abruptly causing local destruction of the concrete. This took place without any significant crack propagation in the concrete prior to the failure. Others separated progressively from the concrete surfaces before failure, making it possible to bridge large cracks (> 3 mm). The ultimate bearing capacity of the beams had been increased by coating up to 70 %. In other words the coating behaved like an additional reinforcement.

In a second series beams coated with different liner materials had been tensioned. The results had been the basis to finally select the coating systems for the containment model.

3.2 Preliminary Results

During the pretests a variety of coating systems had been applied to differently treated concrete surfaces.

In summary the following conclusions can be drawn:

- the adhesion of the liner to the concrete is so excellent that pull-out tests always created a failure within the concrete but never at the interface between resin and the concrete surface or within the laminated layers.
- the influence of the pretreatment of the concrete surface is negligible.
- the liner contributed considerably to the bearing capacity of the tested beams and behaved like an external reinforcement.

- due to its load bearing capacity and its intense contact to the concrete surface the composite liner is capable to branch cracks.
- visible separations of the liner from the concrete surfaces at cracks occur beyond strains of more than 1 %. All the liner systems are able to sustain strains at least upto 1,3 %
- the typical failure mechanism is tearing at the separation area. Successive as well as sudden failures had been observed.

At the beginning of the tests it had been assumed that there is a clear relationship between the crack width at the concrete surface, the area and length of separation and the failure of the liner. This assumption has not been verified by the tests. Obviously the criteria for liner failure is not the crack width of single cracks but the maximum strain at the composite liner system.

Due to the freedom to select the materials of the resins, the glass fibres and their arrangement within the single layers, a relatively large band width of different liner systems can be selected which are all able to fulfill the requirements with respect to leak tightness.

Based on the pretests the following tendencies concerning the stiffness and the adhesion of the liner to the concrete had been identified:

- a high stiffness of the liner is not necessary to provide the leaktightness function
- a high stiffness and a good adhesion to the concrete ensures that the liner can carry relatively high loads. If there is not enough ductility of the liner materials this may lead to a sudden failure of the liner. This should not be a problem, if the sustainable strains before failure are large enough
- a stiff liner with good adhesion to the concrete behaves like a crack distributing reinforcement and thus reduces the crack widths to be bridged
- a good adhesion of the liner to the concrete guaranties that subpressures within the containment or overpressures behind the liner due to temperature effects will not lead to separations. In the case of a local failure of the liner there is no spacial pressure build up behind the liner.
- a poor adhesion allows larger separation areas at single cracks, therefore larger cracks can be bridged.

All the pretests had been performed with beams providing uniaxial strain and crack patterns. At the mock-up the significance of two directional effects with respect to the performance of the liner will be checked.

4 TESTING OF THE CONTAINMENT MODEL

4.1 Description of the Model

The model is intended to represent the cylindrical part of a containment including the transition zone to the basemat which is the most critical area with respect to restraint forces and nonlinear deformations. The scaling factor for the geometry is round about 1:10 and for the pressure loads round about 1:1. A a cross section of the model is presented in figures 2.

The model consists of:

- a cylindrical part with a wall thickness of 20 cm, an inner diameter of 4.20 m and an inner height 3.50 m
- a bottom and a top plate rigidly connected to the cylindrical part with a thickness of 60 cm
- two openings on opposite sides of the cylindrical part and one opening at the center of the top cover plate each with 60 cm in diameter.
- a foundation ring of 1.00 m height on which the mock-up is founded via neoprene pads in order to allow free displacements of the mock-up during pressurization and in order to provide the possibility to inspect the bottom plate from underneath.

The inner part is coated with four different types of composite liner systems so the behaviour of different materials can be studied.

In order to create representative cracks with respect to a real containment relatively large diameters (Ø 28 mm) for the reinforcement had been selected.

4.2 Test Programme

The containment model is designed for a pressure of 6.5 bar_{abs} taking into account serviceability limit state criteria according Eurocode 2. Up to this pressure which is the same as for the pressure test of the EPR the model will behave more or less elastically. The model will be pressurized in different steps upto its ultimate bearing capacity which is expected around 15 bar_{abs}. The test programme consists of three phases.

Phase 1 During this phase the model will be pressurized upto 1.5 bar_{abs} by air. This phase will be used to check the test arrangement and the equipment.

Phase 2 During this phase the influence of temperature variations with respect to the measurements will be checked.

The model will be filled with water. The pressurization will be performed in different steps consisting each of a time for increasing the pressure and a time of round about 20 hours at which the pressure will be kept constant to check whether the model maintains stable conditions. The time is also needed to make inspections and to document intermediate results. If necessary modifications of the test programme can be decided upon.

In a first step the model will be pressurized upto 3 bar_{abs}. At this pressure the first cracks should appear. In a second step the design pressure of 6.5 bar_{abs} will be reached. The composite liner as well as the concrete structure should maintain this pressure without any problems. A detailed inspection of the composite liner will be performed when the water is removed.

Phase 3 Pressurizing upto 6.5 bar_{abs} is repeated by the same procedure as before in order to check whether the model behaves more or less in the same way and meets the serviceability criteria.

The pressure is then increased upto 11 bar_{abs} at which the elastic limit of the reinforcing steel should be reached. Finally the pressure will be increased up to 16 bar_{abs} at which the reinforcement will be in the nonlinear range at a predicted strain level of 0.35 %. At this level a reinforcing steel still keeps a residual strength sufficiently far away from the ultimate bearing capacity. After removal of the water the liner will be inspected and all the measurements evaluated.

The time needed for the tests will be at least 18 days. The pressure versus time function is presented in figure 3.

4.3 *Status of Testing (February 1997)*

The pretests have been finished and evaulated. The construction work of the mock-up had been finished at the end of 1996. It was decided to wait for the liner implementation activities until the end of February 1997 in order to have better weather conditions. The pressure tests will be performed during May 1997, so the results are not available at the time of writing this paper. They will be reported at the SMIRT conference in Lyon.

5 CONCLUDING REMARKS

Within the frame work of the Basic Design for the European Pressurized Water Reactor currently being performed by France and Germany a composite liner is being qualified. Such a liner can be used to increase the beyond design leak tightness of the prestressed containment or to provide the leak tight barrier of the containments with less or no prestressing. The pretests with different composite liner systems already performed are very promising. It is expected that their feasibility will be confirmed by the mock-up at Walldorf which will be tested at the beginning of 1997 and the tests at Civaux end of 1997. The results will be published accordingly.

6 REFERENCES

1. R. Danisch, J. L. Costaz (1995). Discussion on Recent Concrete Containment Designs. *Proceedings of the SMIRT 13 - Seminar 4 on Containment Facilities, August 21 - 22, 1995 Brasilia, Brazil*

2. N. Badez, Y. L'Huby, R. Danisch, H. Hansen. Verification of Leak Tightness of the EPR Containment. *International Conference on Nuclear Containment September 23 - 25, 1996, Cambridge, UK*

3. R. Danisch, L'Huby. Containment Design of the European Pressurized Water Reactor (EPR). *ARS'97, Orlando, Florida, USA, June 1 - 4, 1997.*

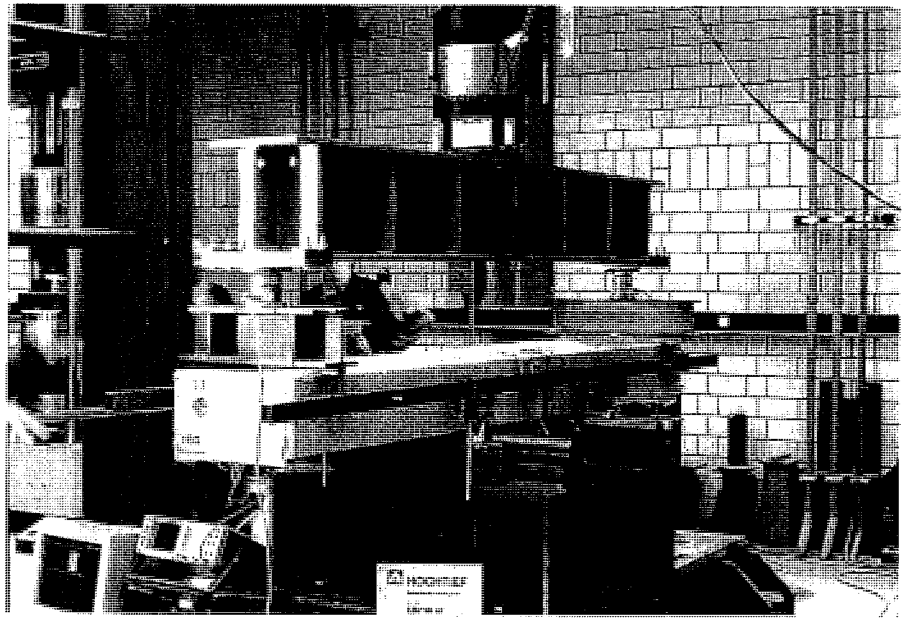

Figure 1: Test Arrangement for Bending Tests

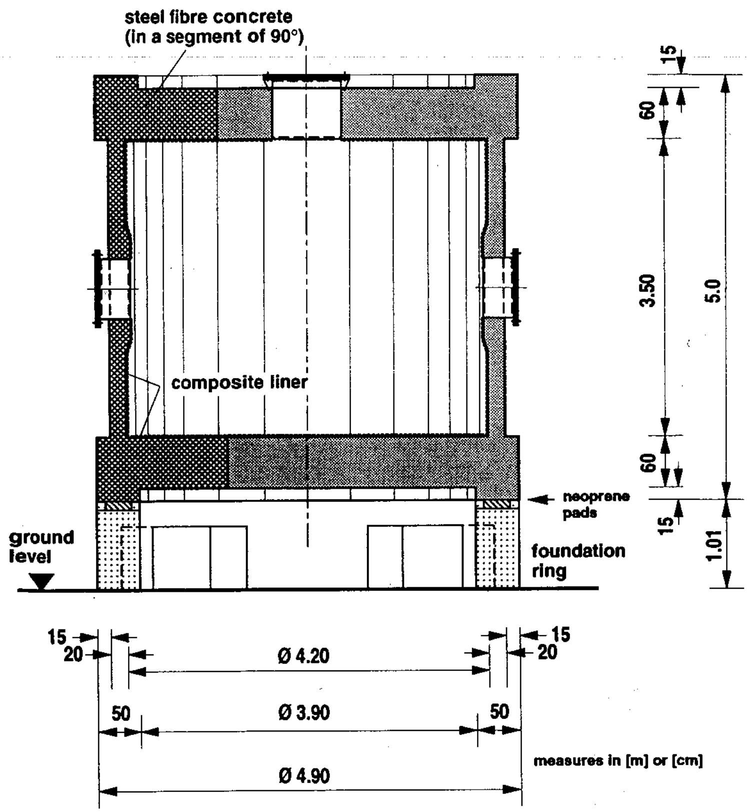

Figure 2: Cross section of the Mock-up

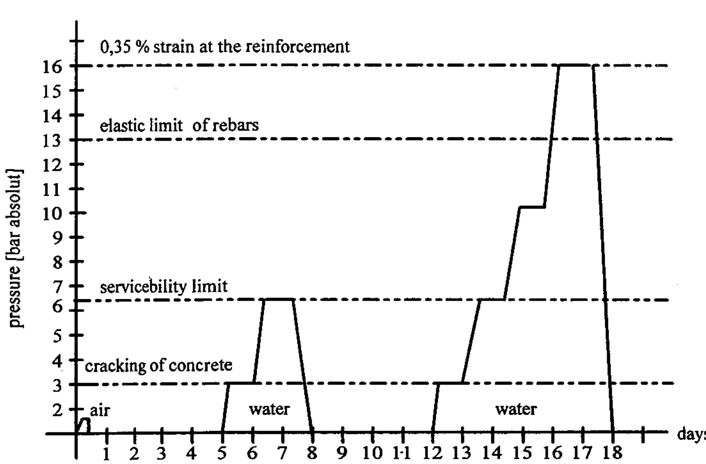

Figure 3: Test programme (pressure versus time)