Multi-layer concept for containments in an integrated construction method by using steel composite building block modules

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ABSTRACT

For the active zone of nuclear power plants, a special composite construction method adopting a multi-layer concept was developed, designed and implemented. The development was performed with the participation and co-operation of enterprises and institutions of the GDR and of the USSR, in particular the Bauakademie (Academy of Building), the VEB Metalleichtbaukombinat (Lightweight Metal Construction Trust) and the BMK Kohle und Energie (Coal and Energy Construction and Assembly Trust) of the GDR as well as the General Planning & Design Office for Nuclear Power Plants "Atomteploelektroprojekt", Moscow, of the USSR.

1 INTRODUCTION

Containments as safety enclosures for nuclear reactors are occupying a dominating position within the total concept for nuclear safety.

With regard to the safety-engineering design of containments, the axiom applies that - with any possible extreme influences acting from within and without - the integrity of the structure must be maintained in order to avoid inadmissible radioactive emissions.

With a view to complying with this requirement, internationally various structural solutions for containments were developed which can be divided into the following two major categories:

- single shell containments
- double shell containments.

Preferentially, both categories are being designed as a composite axially symmetric shell construction. In case of the double shell concept, an outer containment is being erected around an inner containment which is mainly designed to cover failures and troubles in the nuclear zone and to ensure the hermetic enclosure of the radioactive inventory stock. First of all, said exterior containment structure shall sustain the extreme outside influences, among them aircraft impact and shock wave. The clearance between the two containments serves for the controlled dissipation of leakages from the nuclear control area.

In the multi-layer concept for containments in an integrated construction method by using steel composite building block modules as developed for the GDR, a steel plate reinforcement is being arranged and placed at the surfaces of the concrete structure and, in case of need, is being combined with round reinforcing bars inserted in the concrete, with the steel plate reinforcement fulfilling the function of the formwork in the state of construction and the function of the hermetic sealing (surface seal) in the state of operation and damage or failure.

For the further development, a drainage system in the concrete core for the controlled dissipation of leakages through the interior steel plate reinforcement (liner) is envisaged.

2 DESCRIPTION OF THE CHARACTERISTICS OF THE CONSTRUCTION METHOD BY USING STEEL COMPOSITE BUILDING BLOCK MODULES

2.1 Cross-sectional design

The stress and strain which the containment is subjected to by extreme inside and/or outside influences and actions such as overpressure and temperature due to inside damage or earthquake, respectively, aircraft crash and impact, and shock wave, causes high tensile forces in the composite section, first of all in the global system, and locally major shear forces.

Since the cross section is not prestressed, the fully cracked concrete section dominates. Round reinforcing bars in the concrete ensure a fine crack distribution in order to guarantee the radiation shielding. Said round re-bars are required first of all in case of pure membrane states of stress.

With dominant tensile loading, the cross section of a steel composite building block module provided with maximum reinforcement consists of the following four reinforcement layers which, in conjunction with the concrete, are statically effective:

1st layer: Interior steel plate reinforcement with set-bolt dowels for ensuring the composite action (liner)

2nd layer: Reinforcing mat made of round re-bars, immediately behind the interior steel plate reinforcement

3rd layer: Reinforcing mat made of round re-bars, immediately behind the exterior steel plate reinforcement

4th layer: Exterior steel plate reinforcement with set-bolt dowels for ensuring the composite action (with certain prerequisites being given, it can be designed as an additional liner).

In order to accept shear forces, round re-bars are being arranged as transverse reinforcement in normal areas whereas steel plates are being used as transverse bulkheads in areas with very high shear forces.

2.2 Manufacture of the steel composite building block modules

The structural units and members in the composite section (such as steel plates, round re-bars as tensile and transverse reinforcement as well as dowels for ensuring the composite action) are being prefabricated by stationary steel construction companies - integrating also the technological fixtures, inserts and fill members - with a view to providing components capable of being transported and assembled. Said components are designated as steel building block composite modules (hereinafter briefly indicated as steel modules).

The construction trust VEB Metalleichtbaukombinat of the GDR established and equipped specialized production flow-lines for manufacturing the steel modules. The production under factory conditions employing up-to-date manufacturing and testing equipment ensures a high quality. The steel modules are being delivered in a preliminarily preserved condition (e.g. aluminized).

The following basic types of steel modules are being manufactured:

(1) Plane steel modules, e.g. for
- walls with single- or double-sided steel plate reinforcement (see Figure 1);
- floors with steel plate reinforcement arranged at the bottom.

(2) Single-curvature steel modules, e.g. for
- the cylinder of a containment;
- reactor shafts.

(3) Double-curvature steel modules, e.g. for the dome of a containment.

As one can see from the above listing, steel modules are capable of being used in concrete construction not only for containments but, for instance, also in the reactor shaft area as well as with the decaying and recharging basin and with the wall and floor structures within the containment.

For reasons connected with the transportation and handling, the preferential dimensions of the steel modules are about 3,000 x 12,000 mm (with wall thicknesses of approximately 800 to 1,500 mm).

2.3 Pre-assembly

Several steel modules are being welded together into larger assembly units at the pre-assembling yard of the job site. The size of the blocks is subject to the available crane capacity.

2.4 Assembly

With a view to ensuring an exact assembly, special assembling and adjusting facilities and devices have been developed.

The assembly joints are being designed and performed as follows:

1) Plate joints

- double butt strap joints for plate thicknesses of <16 mm;
- butt joints for plate thicknesses of >16 mm.

2) Round re-bar joints

- screwed/bolted connection;
- pressed connection;
- welded connection.

Due to the use of large-size blocks, the assembly joints are being minimized. Up-to-date manufacturing and testing methods and processes are being adopted for this purpose.

2.5 Concreting

The height of a concreting section amounts to a maximum of 5 metres. The concreting work is being performed in lifts (layers) of 400 to 600 mm which are being compacted by means of internal vibrators.

The accessibility of the steel modules - as far as necessary - is being guaranteed by corresponding free spaces or clearances (shafts/manholes, walkways/passages). With a view to ensuring an adequate quality of the concrete, special general instructions and appliances have been prepared and developed such as, for instance, an insertion-type probe operating according to the gamma-ray backscattering method in order to determine the density of the freshly-mixed concrete.

2.6 Economy and quality

As compared with monolithic concrete construction methods using formwork systems in situ, the steel module composite construction method provides advantages first of all in terms of the following:

(1) Considerable economizing of 50% and better of the expenditure of working hours required on the job site with an equal or even a reduced total working time consumption.

(2) Utilization of the steel plate reinforcement as a surface reinforcement and thus provision of a possibility of economizing steel as compared with a linear reinforcement design system using round re-bars.

(3) Employment of up-to-date manufacturing and testing methods and processes with a view to achieving a high quality.

3 SCIENTIFIC AND TECHNICAL INVESTIGATIONS

Research and development work and activities performed for preparing the planning and design and the implementation covered the following fields:

(1) Design and calculation (computation), including the preparation of general instructions (directives), planning and design aids and EDP programmes.

(2) Experimental investigations with structural components and large-scale models.
(3) Development of efficient methods for the manufacture and assembly.
(4) Quality control, development of testing methods and appliances.
The following test complexes concerning para 2 hereinbefore shall be indicated in particular:
(2.1) Test series by means of structural components, e.g.
- for checking and verifying the dowelling and the crack widths;
- concerning the lateral-force loadbearing capacity;
- for simulating an aircraft impact;
- concerning structural details such as wall, floor and foundation connections as well as connection solutions for round re-bars, steel plates and dowels.

(2.2) Tests with large-scale models
- Model of a cubical containment having a side length of 4.4 m and a wall thickness of 0.45 m (safety enclosure/container of the reactor of a nuclear power plant with 440 MWe PWR - design of the USSR)
- Model of an axially symmetric containment having an internal diameter of 9.0 m, a height of about 12 m and a wall thickness of 0.25 m (safety enclosure/container of the reactor of a nuclear power plant with 1,000 MWe PWR, design of the USSR), - see Figure 2.

The results and findings of the theoretical and experimental studies and investigations have been adopted as the basis for the elaboration of special general instructions and directives /3/, /4/.

4 APPLICATION EXAMPLES

4.1 Nuclear power plant with 440 MWe PWR

The first application of the steel module composite construction method was implemented in the GDR with a cubical containment for the safety enclosure of the reactor at the "KKW Nord" nuclear power plant. Subsequently the construction method has been further developed, and at present it is being applied to all containment installations as well. At the "KKW Nord" nuclear power plant, a total number of 8 blocks with an output of 440 MWe each will be built.

4.2 Nuclear power plant with 1,000 MWe PWR

For this plant, an axially symmetric containment made of steel modules has been developed which at present is under construction. Said containment has a diameter of 45 m and is about 60 m high. The wall thickness is 1.20 m. Figure 3 provides a view concerning the division of the containment into assembly blocks consisting of steel modules.

5. CONCLUSIONS

Containments consisting of steel modules have been developed as an alternative design and solution to the double shell containments comprising two separate structures.

The combination of different reinforcement layers of steel plates and round reinforcing bars in one cross section provides a high loadbearing capacity. The multiple utilization of the steel plates in the composite section as formwork in the construction state and as reinforcement and liner in the operation or damage/failure states, respectively, yields a number of advantages.

The main effect is being achieved due to the high degree of prefabrication and completion (finishing) of the steel modules and the reduction of expenditure on the job site connected with same.

REFERENCES

/1/ Friedrich, F. & H. Thomasch. "Stahlzellenverbundmontagebau"; Teil 1: Bauliche Durchbildung. Teil 2: Berechnung ("Steel Module Composite Prefab Construction"; Part 1: Structural Design. Part 2: Calculation); Bauplanung - Bautechnik 30 (1976) 12: 598-600, and 31 (1977) 1: 26-29.

/2/ Friedrich, F. & H. Thomasch. "Die Stahlzellenverbundbauweise - ein neues Bauprinzip für Containments"(The Steel Module Composite Construction Method - a New Construction Principle for Containments); Bauplanung - Bautechnik 38 (1984) 2: 67-70.

/3/ "Technische Vorschrift für die bauliche Durchbildung, Berechnung, Ausführung und Qualitätssicherung von Stahlzellenverbundkonstruktionen" (Technical Specification for the Structural Design, Calculation, Execution and Quality Control of Steel Module Composite Structures); Bauakademie der DDR, Berlin; June, 1982.

/4/ "Vorschrift für die bauliche Durchbildung, Berechnung und Ausführung von Containments in Stahlzellenverbundbauweise (Projektierungsvorschrift)" (Instruction for the Structural Design, Calculation and Execution of Containments by Adopting the Steel Module Composite Construction Method (Planning & Design Instruction)); Bauakademie der DDR, Berlin; November, 1985.

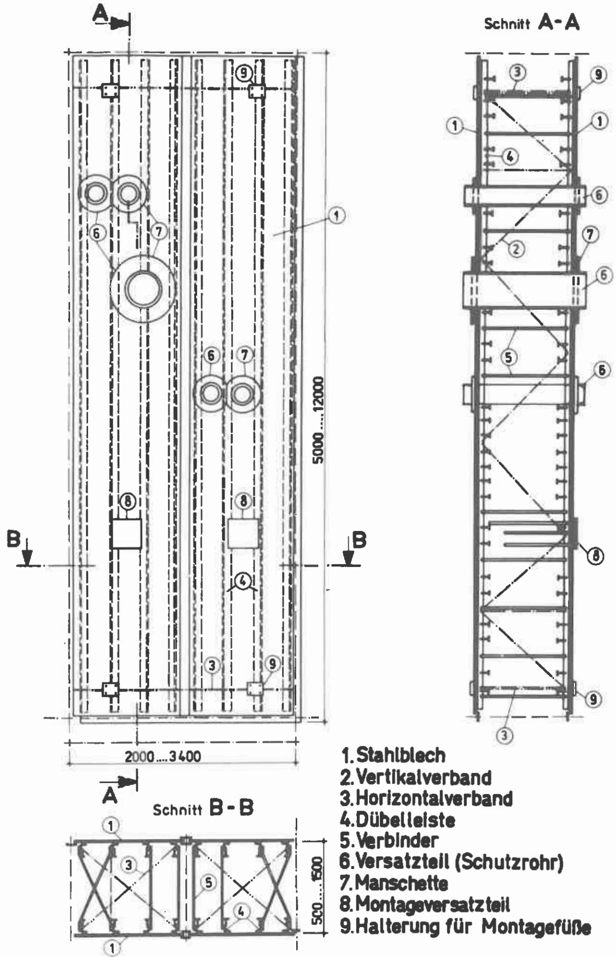

Fig. 1: Plane Steel Module
(NPP with 440 MWe PWR)

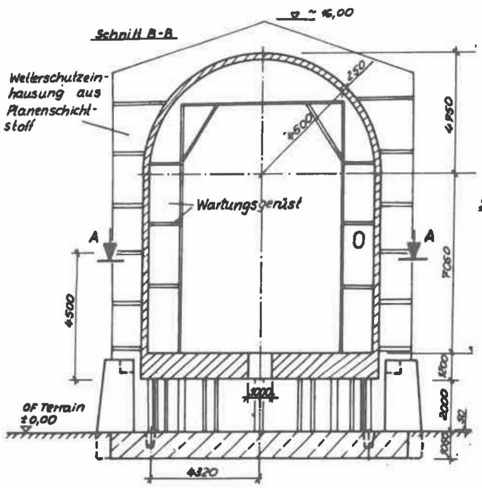

Fig. 2: Test Containment
(M. 1 : 5)

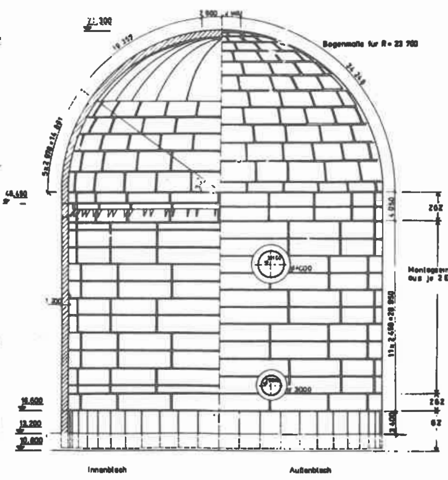

Fig. 3: Containment for NPP
with 1,000 MWe PWR