

RESULTS OF STRENGTH TESTS ON A 1:10 MODEL OF REACTOR CONTAINMENT

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Abstract

A 1:10 scale model of nuclear reactor containment was made of prestressed concrete using materials identical with those of the original structure, with all essential structural details.

It was designed on the basis of the theory of thin shells of revolution.

The tests were carried out in two stages:

- 1/ loading with compressed air at 0.24 MPa overpressure, corresponding to 1.15 of the design pressure,
- 2/ loading with water to a pressure causing destruction.

In the first stage generally elastic behaviour of the structure was established. The influence of buttresses upon the behaviour of the structure was observed.

In the second stage an overpressure of 0.52 MPa at the top of the model was successfully obtained. At this overpressure a considerable loss of tightness occurred. Regular cracking of concrete was observed, and also deformation of mild steel reinforcement. An attempt to break the prestressing tendons proved unsuccessful.

In the paper the distribution of strains and displacements in the individual parts of model is discussed.

1. Introduction

The experimental tests on a model of a containment were carried out in connection with a project for a nuclear power plant with a PWR reactor to be built in Poland.

The 1:10 scale model is patterned on the actual shape and structure of the original and is made basically of the same materials that are used for the actual containment /fig. 1/. The cylindrical part, 11 cm thick, is prestressed with the hoop and vertical tendons. The hoop tendons are anchored in six buttresses, the vertical tendons in foundation slab and in a ring girder. The dome is 8 cm thick. The tendon system of the dome consists of three equal groups, oriented at 120° to each other, anchored in the ring girder.

In those parts of the structure which meet the assumptions of the membrane theory, the post-tensioning causes the forces produced by the overpressure of 0.24 MPa to be reduced to zero.

The tightness of the model is ensured by a liner of 1 mm thick mild steel sheet connected to the concrete by means of thin wire anchors.

The tests were divided into two stages

- a/ tests in the elastic phase, with overpressure not exceeding 0.24 MPa produced by means of compressed air
- b/ destructive static tests of the model with overpressure produced by means of water.

2. Methods of measurements

During the tests, measurement were taken of

- strains in concrete, with the use of electro-resistance strain gauges having a measuring length of 60 mm
- strains in reinforcement and liner, with the use of gauges 3 or 10 mm long
- displacements, with the use of geodetic methods in the stage a, and with the use of induction sensors in the stage b.
- forces at the ends of certain prestressing tendons.

The principal source of errors in measurements taken outside of the laboratory /the model is housed in an unheated shed/ are rapid temperature changes produced by insolation. To reduce these errors, the tests were carried out at night. By measuring the strains in the model without load several times during one night, the error of a single measurement /double standard deviation/ was found to be not in excess of $25 \cdot 10^{-6}$.

Comparing the experimental results with the theory, it is necessary to take into account the errors of the experimental evaluation of strains resulting from nonuniformity of concrete and inaccurate shape of the structure. The magnitudes of these errors were evaluated by comparing in pairs the results obtained from the loaded model at points, where in theory identical strains should occur. The average double standard deviation in such pairs of results amounted to 50.10^{-6} . In view of the fact that the strains analysed subsequently were the mean results obtained at three independent points, it can be assumed that the strains have been experimentally determined with an error not exceeding 30.10^{-6} .

3. The elastic phase tests.

In all loading cycles the model exhibited a satisfactory proportionality of strains to loadings, and the reversibility of strains. No cracks were observed.

The measurement results were compared with the results based upon the theory of thin shells of revolution /fig. 2/. The experimental results are in qualitative accordance with the theory, by virtue of the accordance of signs of the strains and approximate coincidence of extremes and zero points of the diagrams. The basic difference between the theory and experimental findings lies in the substantial disagreement of hoop strains magnitudes. The hoop strains are evidently smaller than theoretical.

The above conclusion is proved in Fig. 3., where the hoop strains on the external cylinder surface reach the minimum at the centre of the segment between the buttresses.

4. Nonlinear behaviour of the model.

In stage b of tests, the difference in pressure between the upper and lower portions of the model was about 0.06 MPa, due to the weight of water. The zero measurement was taken after the model had been completely filled with water, thus the strains and displacements measured were produced by action of overpressure constant at a height. This overpressure shall be further designated p .

During the tests, of major importance were the phenomenons connected with the appearance and development of cracks in concrete. Most data regarding these processes were supplied by the gauges fixed to the reinforcement. The appearance of cracks caused evident changes in the diagram of pressure p - strain ξ .

Fig. 4 shows the relationship $p - \xi$ at selected points of the lower part of the buttress. Horizontal cracks were produced at $p = 0.3$ MPa and subsequently they spread to form a cracked zone on the inside of containment.

The magnitude of reinforcement strains allows to conclude that during the entire test period the lower part of containment was far from reaching the limit strength.

The hoop strains in the middle part of the model /Fig. 5/ are substantially different from those anticipated on the basis of the theory of shells of revolution.

The first cracks appeared in the proximity of buttresses at an overpressure of $p = 0.24$ MPa. With further increase of overpressure appearance of further cracks was observed, nearing the centre of the segment between buttresses.

At $p = 0.46$ MPa all walls were cracked, and a part of hoop reinforcement reached its yield point. The configuration of cracks after tests is shown in Fig. 6.

The measurement of radial displacements of the cylindrical part indicated that the displacements of buttresses are larger than those of wall centres /Fig. 7/ which coincides with the development of cracks observed.

In the surrounding of openings, a major portion of cracks was related to the development of radial cracks, vertical and horizontal /Fig. 6/.

At $p = 0.33$ MPa the crack at the larger opening intersected the entire wall thickness, and the yield point was reached in the reinforcement bar encircling the opening on the inside.

The excess of strength in the surroundings of openings and wall centres was the principal cause of tightness loss in the model at an overpressure of $p = 0.52$ MPa.

The cracks in the dome were randomly distributed, their directions not being related to the directions of main stresses, nor to that of tendons.

Within the portions of dome and cylinder adherent to the ring girder, the yield point of reinforcement was reached.

5. Conclusions

a/ Despite the considerable divergence of theoretical and experimental results, the design worked out on the basis of the theory of thin shells of revolution proved feasible. The destructive pressure, calculated on the assumption of reaching the limit strength of the prestressing steel and the yield point of the mild reinforcement /without cooperation of liner/ amounted to 0.49 MPa, and with the liner - 0.62 MPa. The experimentally obtained values were 0.52 MPa at the top, and 0.58 MPa at the bottom of the model, which can be considered equal to expectations.

b/ In order to increase the resistance of containment to cracking, the non-prestressed peripheral reinforcement at the openings and at the

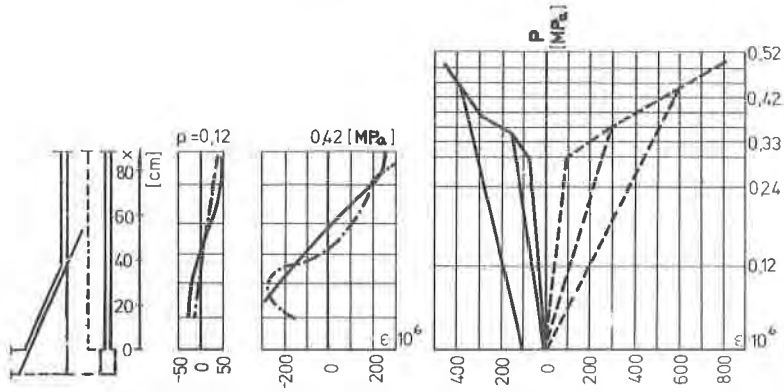


Fig. 4. Vertical strains in the lower part of buttress.

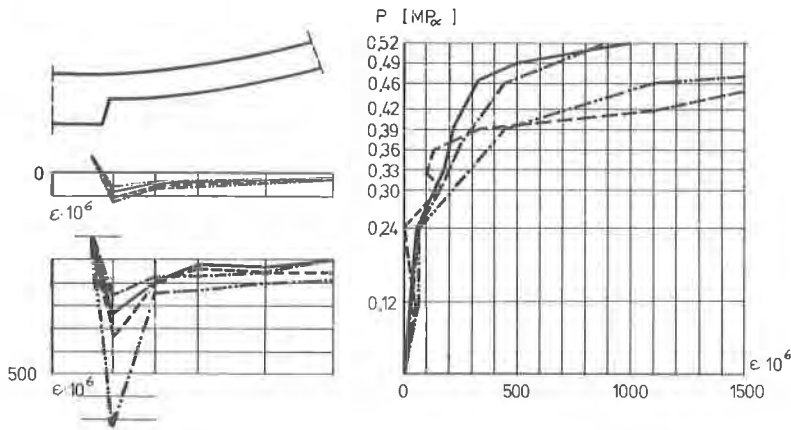


Fig. 5. Hoop strains at model mid-height.

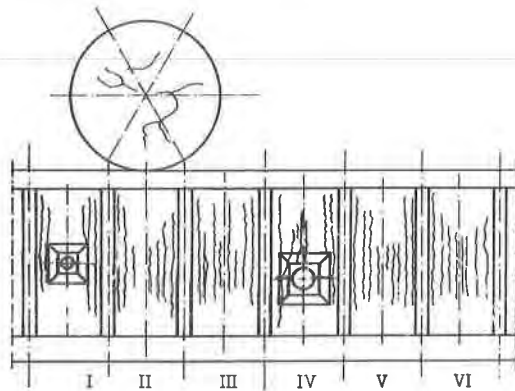


Fig. 6. Diagram of cracking of model external surface after tests.