WORK ON REACTOR VESSELS OF PRESTRESSED CONCRETE IN YUGOSLAVIA

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The design for a two-wall concrete reactor pressure vessel model has been developed in Yugoslavia. The external vessel is prestressed with steel cables in the usual way. There are no cables in the internal vessel and this vessel is prestressed by a hydraulic system, inserted between the outer and the inner vessels. Calculations show that, for such a vessel conception, economies could be made for about 25 percent in cables and about 40 percent in concrete, using at the same time the same prestressing as for single walled vessels. At present, the model of such a vessel type is under construction in the Institute of the SR Serbia for Testing Materials in Beograd. The results of mathematical analyses of the action of seismic forces are discussed.

No Nuclear Power Plant has as yet been constructed in Yugoslavia, its construction, however, is being considered for the next years. Therefore it cannot be the question of an own experience in this field, except for some investigations made in the past years.

Relying on the Swedisch conception of the BHW reactor, studies were started here on the home possibilities for the construction of a prestressed concrete pressure vessel for a 200 to 500 MW Power Plant.

In the first phase of this research, fairly detailed designs for the said pressure vessel were developed, leading to a better understanding of the problems to be faced with in this connection.

One of the most serious problems, set before any constructor of prestressed concrete pressure vessels, concerns the temperature in the vessel and the stresses caused by its gradient.

It is a well known fact that, by enlarging the wall thickness, thermal stresses are not efficiently reduced, which means that the thermel stresses have to be covered by prestressing correspondingly the whole concrete cross section. Besides the waste of steel, this increases the difficulties in the location of steel cables and leads to extremely high pressure stresses on the internal margine of the concrete cross section at the moment when the reactor is put out. Normally, a solution for this problem is sought in the construction of a sufficiently efficient insulation which is to protect the concrete against the high temperature reigning inside the vessel and to reduce the temperature difference between the in- and outside margines to an acceptable gradient.

But, on principle, the temperature gradient could be made acceptable also with a less efficient and cheaper inside insulation, provided we adopt a cheap outside insulation, raising the temperature at the outside surface to the desired height. This would naturally increase the temperature of the concrete as a whole to a some higher level. The determination of the temperature, at which a concrete pressure vessel could be technically successfuly and economically designed, is, no dount, a complex task, and it can be solved only after long and expensive tests.

Regardless, however, of the future answer to this question, we think that, with some insulation and heating of the outward vessel surface, along with the inside insulation, used so far, economies could be obtained which would justify the application of such a solution, and would yield at any rate a more convenient state of stresses.

Considered was also the question of two-wall concrete vessels. The conclusion was reached that, by inserting a hydraulic system between the external and internal vessel, one could exercise an active influence upon the whole state of stress in the vessel.

To this purpose a design for a two-wall pressure vessel model has been developed. The external vessel is prestressed with steel cables in the usual way. In the internal vessel there are no cables, and this vessel is prestressed by a hydraulic system, inserted between the outer and the inner vessels. The wall thickness of both vessels, the quantity of cables in the external vessel, and the hydraulic pressure in the system between the vessels have been determined so as to satisfy the following conditions:

(a) At full loading of the reactor the stresses at the critical points in both vessels come down to zero (or to a minimum determined pressure) so that the whole system is fully compressed.

(b) When the reactor is put out but the vessel is still hot, the critical stresses in both vessels do not exceed the maximum desired pressure. This is obtained by a reduction of the pressure in the middle hydraulic system to a determined quantity (e.g. to 1/2 of the pressure necessary for prestressing the vessel at full load).

Simultaneously the inserted partition can serve also as a temperature regulator in the vessel both, when setting the vessel into operation and in the course of its running.

Calculations show that, in this way, economies could be made for about 25 percent in cables and about 40 percent in concrete, using at the same time the same prestressing as for single walled vessels. The hydraulic system in the partition will cost, of course, a certain amount which reduces the effect of the said economies.

To such a vessel conception, besides the remarks concerning the introduction of the hydraulic system which becomes an active element in the functioning of the vessel, remarks are usually made which are common to all two-wall constructions, insofar such constructions intend to make economies in cables. It is the question of the safety factor at failure.

It is commonly known that the ultimate bearing capacity of concrete vessels practically depends exclusively on the quantity of steel cables in the vessel. In some countries a safety factor at failure of 2.5 is requested for pressure vessels. This is the usual measure applied to constructions of bridges and buildings in prestressed concrete and it is always met with, if the norms are respected concerning the allowed stresses in concrete and steel.

However, if we consider a pressure vessel construction which, abiding by all the other conditions, makes economies for a determined quantity of steel, the request that the safety factor at failure should attain 2,5 will possibly not be met with. In our conditions, one half of the cable economies is due to the geometry (smaller cable circle) and this part has no influence upon the reduction of the safety coefficient at failure. In other words, the safety coefficient for cables at failure would be 2,25.

It is a question whether such a demand is justified. To our opinion, the safety of pressure vessels should not be estimated by the load which tears the cables but by the load which produces fissures. A vessel with fissures becomes dangerous much earlier than the whole bearing capacity reserve, massed in the cables, is exhausted.

The said model of a double vessel has been developed on the conception of preserving the safety against occurrence of fissures. Herein, it should be kept in mind that it is indispensable to preserve against fissures only the inner vessel, while in the outer vessel, in case of an accident, fissures can be admitted. By increasing the pressure in the hydraulic system of the partition, it is possible to maintain the inner vessel in a state without fissures even at a considerable increase of the pressure within the vessel, wherein the outer vessel will suffer more or less fissuring, or will remain untouched depending on the quantity for which the pressure in the vessel has been raised. In short, it is possible to preserve the inner vessel to be intact, without fissures, practically quite near the pint of failure of the outer vessel, on condition that the hydraulic system of the partition is not too inert.

This property of such a two walled vessel, namely, that its safety factor against occurrence of fissures can be raised considerably above the usual values, makes it essentially different from the one-wall vessels and makes its model testing worth while.

At present, the Institute of the S. Serbia for Testing Materials in Belgrade is occupied with the construction of such a model in order to verify the advanced statements.

Parallelly with this tests are being made with a steel wirde for cables at increased temperatures. Tested were wires Ø 9 mm of Austrian origine. Mechanical properties of the wire, , including relaxation, were investigated at temperatures of 50-100-150 and 20 °C through a period of 30 days.

Based upon these tests we conclude that, at least what the wire is concerned, the temperature of the concrete, in which the wires are placed, could be somewhat raised. The increase of the relaxation at the temperature of 50 °C is very small as compared with the relaxation at the room temperature. This increase is tolerable even at a temperature of 100 °C. At higher temperatures the relaxation considerably increases so that it is a question whether a further raising of the temperature is technically and economically justified.

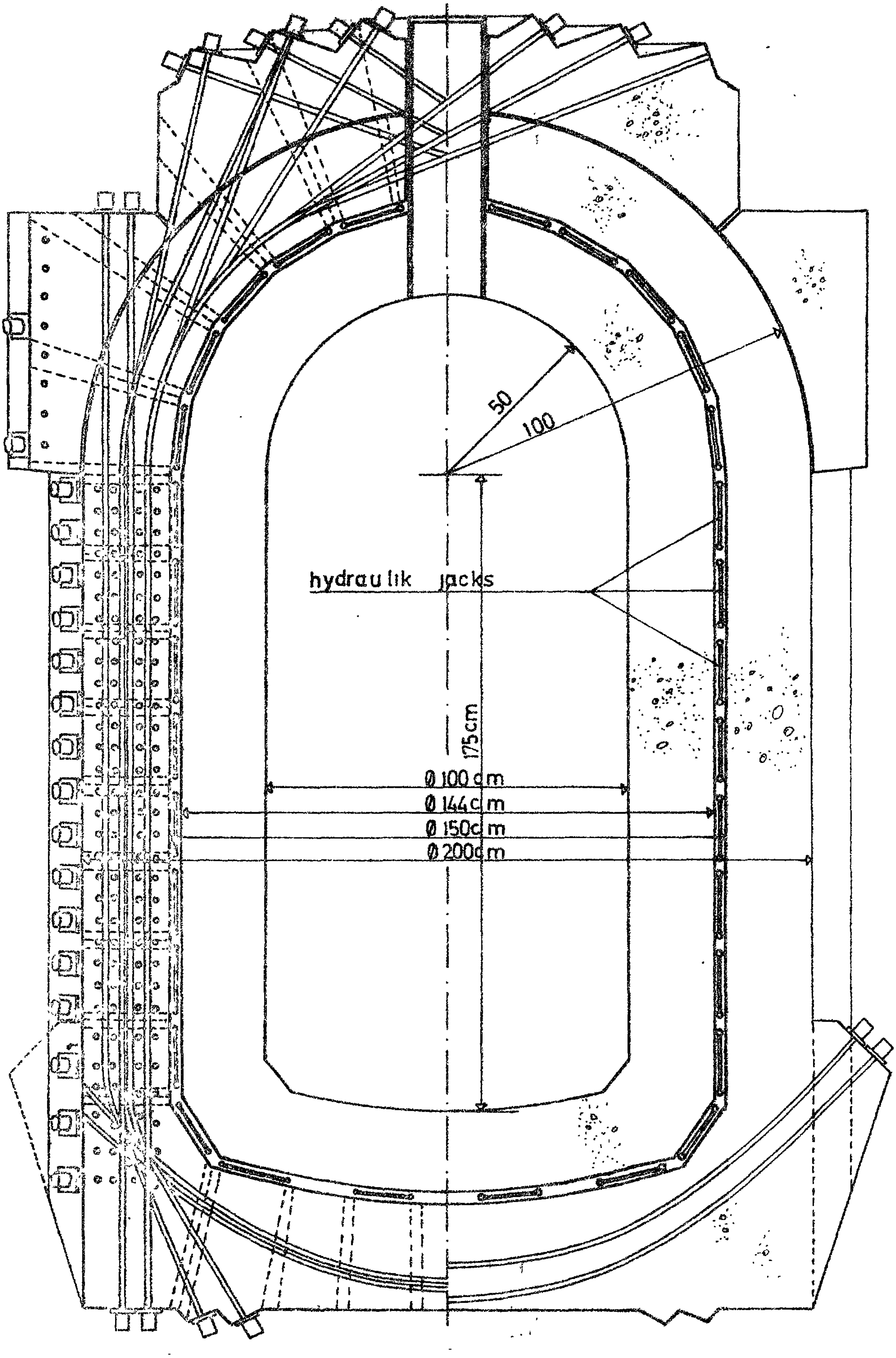
On the other hand, if by the external insulation of the vessel the temperature gradient on its surfaces would be lowered for about 20 - 30 °C, the thermal stresses and the quantity of steel for their covering would be considerably reduced. Since, with all that, we remain within the limits of temperature of 50-70 °C, we would not expect an essential change of the behaviour of the steel for the cables.

Parallelly with the wire tests, concrete investigations at increased temperatures were organized too. A series of tests of a selective character with micro-concrete has been organized wherein cements were selected which would come into consideration for further investigations. In the course are preparations of tests referring to the behaviour of concrete at increased temperatures which shall start in 1970 and which will give, as we hope, an answer to the question at what temperature pressure vessels of prestressed concrete can be technically and economically designed and realized.

Since a great part of the Yugoslav territory is potentially exposed to the action of seismic forces of destructive power and since the location of future nuclear power plants is possible for the greater part just in such regions, the analysis of the action of seismic forces upon such installations has been approached too. So far, such investigations were made exclusively by means of mathematical analyses, but the construction and test of a certain number of simple dynamic models are provided for.

Based upon the mathematical analyses made so far, we should say, that massive concrete pressure vessels, if they are well founded, are not directly endangered by the action of seismic forces. But this need not refer to the elements of the reactor core, the pipelines and the systems outside the pressure vessel. For the moment a greater attention was given to the study of the behaviour of the inflammable elements, as well as of the bars for checking and putting out the reactor.

Analyzed were mathematical models of these oscillations while model investigation of the behaviour of the core elements during an earthquake is provided for.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