# Preliminary design of two buttress prestressed concrete containment for a VVER 440 MW PWR

J.S.Whitcraft, Jr. & M.Daye
*Bechtel Eastern Power Corporation, Gaithersburg, Md., USA*
P.Varpasuo
*Imatran Voima Oy, Helsinki, Finland*

## 1 INTRODUCTION

The standard design for a VVER 440 MW pressurized water reactor does not include a containment vessel. As part of a preliminary design for a VVER 440 MW station to be constructed outside of the USSR, several concrete containment configurations were evaluated.

This paper reviews the work done for three prestressing system configurations applied to two containment geometries.

## 2 CONTAINMENT CONFIGURATION

Two containment configurations were evaluated. The first consists of a right circular cylinder founded on a flat slab with a hemispheric dome roof. This design has been developed by Bechtel Power Corporation for use on PWR's up to 1200 MW in size (Ref. 2). The second containment is also a right circular cylinder on a flat slab but with a torus-spherical dome and ring girder. This design is similar to early US containments and is the configuration presently used on the VVER 1000 MW PWR's (Ref. 1).

The dimensions of the containments were chosen so that both have a radius of 21.00 meters with a gross interior volume of 73000 cubic meters. The hemispheric domed containment is shown in Figure 1. It has a height to the springline of 38.73 meters with a dome radius of 21.00 meters. The torus-spherical containment, shown in Figure 2, has a central cap with a radius of 30.53 meters and surrounding torus of radius of 11.47 meters. Its height to springline is 43.35 meters.

## 3 PRESTRESSING CONFIGURATION

The prestressing system arrangements evaluated in these two containments are significantly different.

In Bechtel standard designs, the cylinder wall is prestressed using tendons placed in an orthogonal array. In the circumferential direction, hoop tendons are arranged horizontally around the shell and anchored to three buttresses 120 degrees apart. Tendons extend 240 degrees around the cylinder, being anchored at alternate buttresses. Three tendons then overlap to form two complete hoop tendons. In this work, the use of two buttresses 180 degrees apart has been evaluated.

Hoop tendons extend around the entire circumference of the cylinder so that both ends are anchored at the same buttress. Every other tendon is anchored on the same buttress.

For containments with a hemispheric dome, the dome and the wall in the meridional direction are prestressed by a single set of tendons. These tendons loop over the dome and extend down through the walls so that both ends are anchored in the tendon gallery below the foundation slab. These inverted U tendons are arranged in two orthogonal groups in the dome to provide prestress in both directions. Hoop tendons are also required to provide circumferential prestress in the lower portion of the dome up to an angle of 45 degrees from horizontal.

In the torus-spherical domed containment, dome tendons are arranged in two orthogonal groups, as for the VVER 1000, with anchorages in the exterior of the ring girder. These tendons provide two directional dome prestress independent of the cylinderical shell.

With a torus-spherical dome, the cylinder may be prestressed in several ways. Meridional and circumferential prestress can be applied by independent vertical and hoop tendons, respectively. The vertical tendons are anchored below in the bottom of the foundation slab and above in the top of the ring grider. Hoop tendons are anchored in two or three buttresses as described above. Alternatively, as adopted in standard VVER 1000 MW containment, both meridional and circumferential prestress are applied simultaneously using helical tendons anchored in the tendon gallery below the slab and in the top of the ring girder. These helical tendons are arranged in two groups, sloping in opposite directions.

## 4 PRESTRESSING MATERIAL QUANTITIES

In all, five prestressing system/containment combinations were evaluated. A hemispheric domed containment with either two or three buttresses, and a torus-spherical domed containment with two buttresses, three buttresses or helical tendons.

Similar assumptions were used in all cases so that the prestressing system quantities developed are directly comparable. A prestress level of 1.25 times the design pressure (excluding all other loads) was chosen. It is assumed that all tendons are stressed from both ends. Additionally, the following parameters, determined by Imatran Voima Oy, were used:

| | |
|---|---|
| gross free volume | 73000 cubic metres |
| internal design pressure | .35 MPa |
| concrete strength | 31 MPa |
| initial shrinkage strain | 125 microstrain |
| creep strain | 590 microstrain |
| wobble friction coefficient | .002 /metre |
| angular friction coefficient | .2 /radian |
| tendon relaxation loss | 2.5 % |
| tendon material strength | 1760 MN/sq. metre |
| tendon area | 51.2 sq. cm (55 strands) |

Using these parameters, the design requirements of ASME Section III, Division 2, and standard design practices, the following prestressing material quantities were determined:

Hemispheric Dome

| | Two Buttress | | Three Buttress | |
|---|---|---|---|---|
| | Tendon No. | Total Length (m) | Tendon No. | Total Length (m) |
| Cylinder Hoop | 82 | 11640 | 105 | 10080 |
| Dome/Hoop | 18 | 2210 | 18 | 1510 |
| Dome/Vertical | 80 | 11200 | 80 | 11200 |
| Total | 180 | 25050 | 203 | 22790 |

Torus-Spherical Dome

| | Two Buttress | | Three Buttress | |
|---|---|---|---|---|
| | Tendon No. | Total Length (m) | Tendon No. | Total Length (m) |
| Vertical | 90 | 4770 | 90 | 4770 |
| Hoop | 94 | 13350 | 117 | 11230 |
| Dome | 80 | 2880 | 80 | 2880 |
| Total | 264 | 21000 | 287 | 18880 |

Torus-Spherical Dome with Helical Tendons

| | Tendon No. | Total Length (m) |
|---|---|---|
| Helical | 436 | 37930 |
| Dome | 80 | 2880 |
| Total | 516 | 40810 |

## 5 EVALUATION OF CONTAINMENT AND PRESTRESSING SYSTEM FEATURES

### 5.1 Design

Regardless of the containment geometry and prestressing system configuration, the containment design process is essentially identical. First, preliminary proportioning is performed to establish the design loads, prestressing requirements and vessel component thicknesses. Then a detailed design of the vessel is performed, using classical or finite element methods, to determine nonprestressed reinforcing requirements that result from all design bases load combinations.

The final analysis normally consists of separately evaluating axisymmetric and non-axisymmetric load combinations. Axisymmetric loads, such as dead and live loads, prestress, internal pressure and thermal conditions are easily performed on a containment with a hemispherical dome using classical methods. For a rigorous analysis of a torus-spherical dome with ring girder, it is prudent to use finite element methods because of the complex prestressing loads applied to the ring girder and the similarly complex and congested non-prestressed reinforcing that results.

The prestressing system chosen effects details of the final containment design. ~~For example~~, it is preferred to not apply circumferential prestress near the bottom of the cylinder. The local transverse shear in the shell that results from restraint imposed by the foundation slab will be reduced. Using an orthogonal tendon arrangement in the cylinder, with two or three buttresses, it is possible to do this by leaving out several hoop tendons at the bottom of the shell. Using helical tendons, which anchor below the slab, the circumferential prestress is applied over the entire shell wall. This will induce transverse shears which, depending upon the level of prestress, may be large enough to necessitate thickening the shell at the bottom to form a haunch. This haunch then locally increases the shell stiffness attracting still larger moments and shears. The result is additional meridional and circumferential reinforcing in that region.

The helical tendon arrangement does have a layout advantage. Since no buttresses are required on the cylindrical shell, the entire shell surface is available for penetration by process piping and electrical conductors. However, there may be some problems with large penetrations because of the requirement for extensive realignment of closely spaced helical tendons sloping in opposite directions.

## 5.2 Construction

Construction aspects of the various containments and prestressing system arrangements have a significant impact on overall costs.

The construction of the ring girder for the torus-spherical dome is a difficult, costly process. The numerous tendon anchorages, for intersecting dome and helical tendons, set at continuously varying angles, with the congested nonprestressed reinforcing, requires careful planning to assure efficient execution.

Positioning of ducts for an orthogonal tendon system is relatively straight forward. Duct location and elevation can be readily established and field verified. By comparison, the positioning of helical tendon ducts, even using shop pre-assembly methods for wall panels, is difficult and exacting work.

As can be seen from the quantities shown above, a large number of helical tendons are required. The tendon slope of 37 degrees from horizontal, (the optimum slope depends upon the coefficient of tendon friction), produces unnecessary meridional prestress. This inherent inefficiency results in substantial addition material to be installed.

# 6 CONCLUSIONS

Use of a containment with a hemispherical dome and two buttresses has several advantages over the other configurations evaluated. These are:

a. A ring girder is not required. Construction of the cylinder and dome can be performed without delays associated with the installation of numerous tendon anchorages and complex reinforcing.

b. The number of tendons is minimized. While some additional tendon material is needed over that for a torus-spherical domed containment with buttresses, the field tendon installation and stressing time is reduced. With normal labor vs material costs, this scheme should be the least cost of all the alternatives.

c. The positioning of ducts for orthogonal tendons is simpler than for the helical layout.

d. The tendon material quantities needed for an orthogonal system are substantially less than for the helical arrangement.

REFERENCES

1. Dubrovsky, V., "Construction of Nuclear Power Plants", translated from Russian by A. Duznetsov, Mir Publishers, Moscow, 1981.

2. Reuter, H. R., and Whitcraft, J. S., Development and Optimization of Containment Structure Concepts, C125/75, International Conference on Experience in the Design, Construction and Operation of Prestressed Concrete Pressure Vessels and Containments for Nuclear Reactors, York, England, 1975.

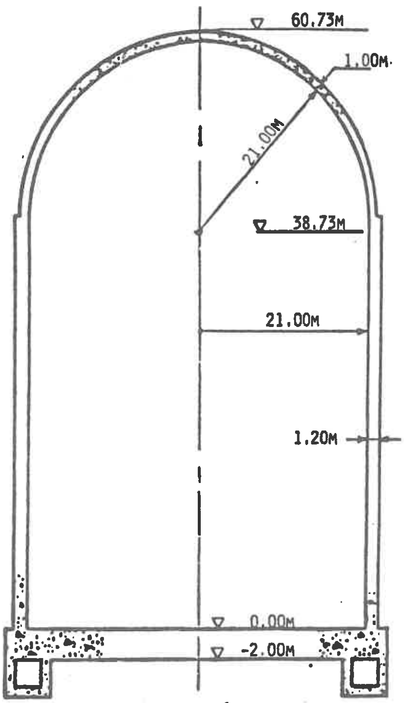


FIGURE 1

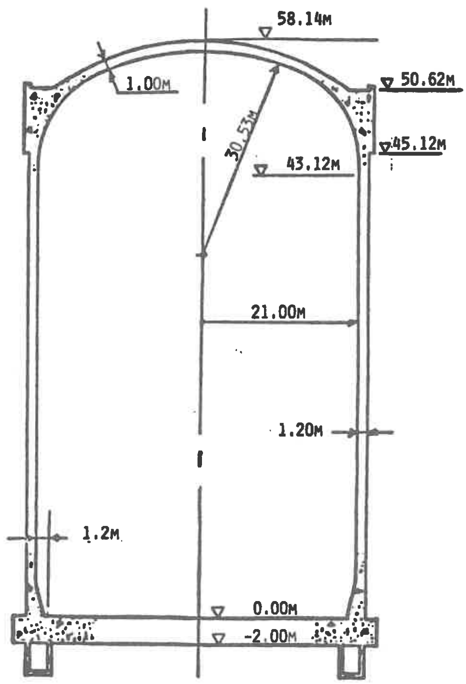


FIGURE 2