

The Dome of Daya Bay Containment Design and Construction

J. PICAUT, J. F. SIDANER

COYNE et BELLIER, Bureau d'Ingénieurs Conseils, Paris, France

G. PASTOR

Electricite de France, CIG, France

J. LORTEAU

Campenon Bernard, France

1 INTRODUCTION

The Guangdong Nuclear Power Plant Joint Venture Company (GNP JVC), responsible for owning and operating the Guangdong station, signed in 1986 contracts with Electricité de France, Framatome, GEC Turbine Generators and signed in 1987 a contract for civil works of Nuclear and Conventional Island with a joint venture led by Campenon Bernard of France and Maeda of Japan associated with two chinese companies HUA XING and SBC for the supply of two 900 MW PWR.

The reference plant for the Nuclear Island is the French Gravelines 5-6 which entered in operation in 1985. The project schedule allows for about 72 months between authorization to proceed and commercial operation for unit one.

The Guangdong nuclear power station is located on the southern coast of the People's Republic of China in the Guangdong province. The site is located east of Shenzhen city and west of Daya Bay.

2 ORGANIZATION OF THE PROJECT

The overall project management activity was implemented by GNP JVC in close collaboration with Electricité de France which performed:

- Technical Management of the project for both engineering and on site activities.
- Civil design of the Nuclear Island and Balance of Plant (BOP).
The design calculations and all construction drawings of the Nuclear Island were performed in accordance with the usual practice in France as well as for Export projects by the two French Consulting Engineers : COYNE et BELLIER and SECHAUD et METZ, the containment design being in the scope of COYNE et BELLIER.
- Design Review and monitoring of manufacturing activities.
- Licensing and commissioning.
- Training services.

The Nuclear Island civil works were designed in France and an advanced team on site including personnel from EDF and COYNE et BELLIER ensured the necessary design interfaces with the site contractors and particularly civil works contractors.

3 GENERAL CHARACTERISTICS OF CONTAINMENT

The overall geometry of the containment is shown on fig.1. The dimensions of the superstructure are practically identical to those of the French Reference plant. However the different site conditions led to an increased raft thickness. It was also necessary to readapt the prestressing and reinforcing steel patterns in the whole structure due to site conditions, to taking into account feedback of experience from the French 900 MW series and also changes in regulations.

3.1 Geometry of Containment

900 MW	
Inside diameter	37m
Overall inside height	60.38 m
Raft thickness	5.0 m
Cylinder wall thickness	0.9m
Dome thickness	0.8m
Inclosed volume	63,000m ³

3.2 Overall quantities

	Concrete Volume (m ³)	Reinforcing bar (tons)	Prestressing steel (tons)
Raft	6650	1200	
Cylinder	6200	900	370 + 620
Dome	2450	300	180
Total	15300	2400	1170

Liner: Area = 8900m² - Weight = 630t.

3.3 Main loads and site conditions

The Nuclear Island is built on fresh or slightly weathered hornfels on a granitic intrusion in sedimentary rocks. After geotechnical tests (static and dynamic) such a foundation can be defined as firm rock for raft and superstructure design. The plant is located in a moderate seismic region. Based on available seismic data from 288 AD to present, a seismotectonic study enabled the definition of seismic design parameters: the ground response spectrum used for the Nuclear Island is the spectrum defined in USNRC: regulatory guide 1.60 with a maximum horizontal ground acceleration of 0,2 g for safe shutdown earthquake level.

Design of the containment took into account adverse situations which may occur such as severe pipe rupture of the primary system. Leaktightness is ensured by a steel liner and the

prestressed concrete containment is designed to sustain internal pressure during LOCA or pressure test. Design pressure is 0.42 MPa.

The prestressed containment protects against external hazards such as:

- shock waves due to an external explosion,
- civil aircraft impacts according to French regulations,
- tornadoes and tropical cyclones defined as extreme climatic loads including impacts occurring with these events.

3.4. Design criteria

All the load cases are classified according to the French nuclear regulation (RCCG) in four categories :

- loads during construction
- normal design loads
- increased design loads
- special design loads

Each of them is related to a specific design criteria according to the French prestressed concrete regulations for working stress design and ultimate load design with adequate safety factor. The containment's basic design load cases are test pressure and LOCA condition. In such a case, prestressing is designed to maintain overall global compression in concrete. Specific verifications are made for a special design case defined as LOCA plus Safe Shutdown Earthquake especially in the lower part of the containment.

3.5 Prestressing

The prestressing of the containment is achieved using the Freyssinet prestressing system with post-tensioned steel tendons with 19 or 36 strands per tendon.

Prestressing of the dome is independent of cylinder prestressing.

The cylinder's horizontal cables are 19 T 16 tendons placed on two layers, anchored on four ribs, 360° round the wall. They are tensioned from both ends. Spacing is 0.22 m. Vertical prestress is ensured by 37 T 16 tendons from bottom to crown. The 144 vertical tendons are tensioned from one end.

Dome cables are 19 T 16 tendons spaced in a regular triangular pattern with three layers, with a spacing of 0.53m.

Cables were placed one strand at a time. Ducts and tubes were grouted after tensioning.

4 DOME

4.1 Geometry of dome

The dome of the 900 MW PWR consists of a standard spherical part (thickness 80cm, inside radius 24m) overlaying a perimeter torus segment of 6m radius making the junction between the dome and the cylinder.

4.2 Basic comparison between Daya Bay dome and complete hemi-spherical dome

The choice of the dome geometry has a large influence on overall design including cabling.

The Daya Bay concept allows for :

- a higher metallic dome liner, with a higher cylinder wall,
- a lower dome which although thicker at the crown does not lead to an increased overturning seismic effect,

- a simpler prestressing pattern enabling the use of a different type of cable in the dome and the cylinder allows to minimize the dome's thickness,
- easier installation of cables (one strand at a time)
- a gallery under raft of reduced dimensions as it is not used for introducing cables.

However it may be questioned whether stresses in the dome are adequately uniform during construction (prestressing phases), during normal operating conditions and finally during pressure test (or LOCA). It may also be questioned whether construction problems are not more difficult to solve and particularly:

- shuttering the crown and the spherical part,
- installing anchor heads in crown area, and ducts in the crown and the central part,
- concreting the crown and the spherical part in successive lifts.

4.3. Design calculations and stresses in the dome

The final design of the dome is done using a tridimensionnal finite element model. In such a model, the exact pattern of prestressing tendons is introduced to obtain the correct stresses distribution in the concrete across a standart section of the dome, and the torus segment. Specific computer programs were developed by Coyne et Bellier for this use.

This final design models the successive prestressing phases in order to assess the stresses in concrete during prestressing and the different construction phases:

- . phase 1 : one third of dome tendons,
- . phase 2 : two third of dome tendons,
- . phase 3 : end of cylinder prestressing,
- . phase 4 : end of prestressing.

Radial compressive stress is lightly smaller in the centre of the dome than in its mid part. The stresses are almost uniform around the containment during prestressing phases and normal operating: they are isotropic.

Due to the stiffness of the torus beam, inside pressure effect and prestressing forces decrease at the periphery, the result being a small compressive stress during LOCA or pressure test.

Special attention was payed to shear stresses during the prestressing phases to avoid unbalanced forces. Bending stresses in the torus segment act mainly in normal operating as compressive forces; the internal face is always in compression. Those bending stresses are lower in accidental conditions, due to the opposing effect of the internal pressure and to prestressing.

The torispherical dome design leads to a larger radius on the spherical part than for a pure spherical design. Spacing of tendons is reduced in the standart part of the dome, but the overall quantity of prestressing steel is not affected by the geometry : the form of the dome reduces the forces in the torus segment and also the quantity of tendons in this area.

It is easier to install a larger number of ducts or tubes in the central part of the dome where slope is small: the formwork of the dome contributes to achieving satisfactory prestressing of the containment in the time period allowed.

4.4 Erection of the Dome and Construction aspects

The erection phases were:

- a) Fabrication of the metallic parts of the dome and perimeter torus on the ground near the containment in two complete halves from quadrants delivered from the factory. The two halves were then hoisted separately and welded to the steel liner at level (44.83). The two halves were then welded together.
Of course this operation took place after erecting the polar crane.

- b) Concrete is poured for the top of the cylinder and the perimeter beam up to level (49.50).
- c) Twenty centimetres of concrete were poured between the steel angles in the spherical dome to provide the extra stiffness needed to support the mass concrete.
- d) The pouring of the perimeter beam was then completed and the vertical cables partly tensioned.
- e) The spherical part of the dome was concreted in lifts.
The concrete is poured in continuous layers in the perimeter beam and the rim of the spherical dome.

Formwork of the dome did not induce difficulties:

- For construction the crown can be made with the same formwork as for the cylinder, the external part being vertical.
- The dome itself is then poured in successive lifts allowing the use of a limited formwork without need of support which can be used with little modification for all the lifts of the dome. The formwork has detachable parts in order to allow an easier pouring and vibration of concrete. The upper part is poured without formwork.
- The anchor heads in the crown are maintained at their accurate location with special boxes fastened to the vertical formwork.
- The formwork between different lifts is made by wire netting which must be placed carefully at the right time before, during and after the prestressing ducts and reinforcement installation.

In general there is no particular difficulty for this kind of dome.

4.5 Schedules

The overall schedule for containment civil works is given hereafter:

The sequences are shown on the schedule:

- erection of the cylinder,
- lifting of the polar crane and the dome (the dome has a temporary support on the top of the polar crane)
- welding of the dome,
- construction of the crown,
- the vertical prestressing can be done at the end of the crown allowing the horizontal prestressing and the finishing of peripheral buildings,
- end of the dome (without incidence on the overall schedule).

The works have been done according to the initial schedule for UNIT 1 and in advance for UNIT 2.

5 CONCLUSION

The design of the dome of the Daya Bay Containment achieves satisfactorily the objectives assigned for such a nuclear structure:

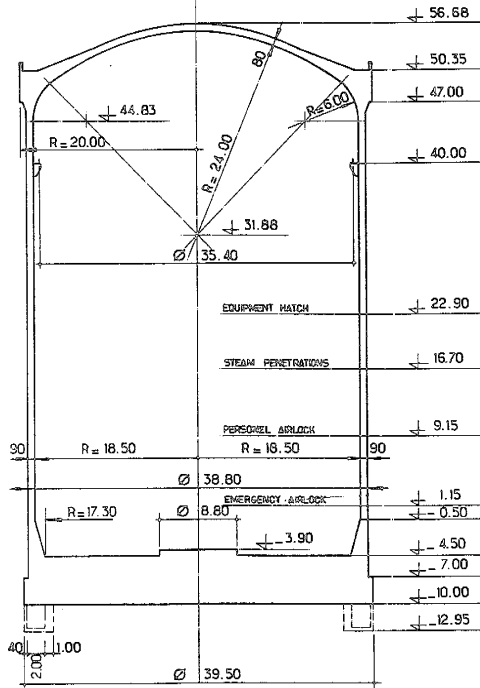
- adequate safety margin for design loads,
- adequate construction methods, contributing to achievement within a tight schedule.

It is worth using a sophisticated design to facilitate construction.

GUANGDONG NPS
REACTOR BUILDING _ CONTAINMENT

Fig.1

Vertical Cross Section
Scale : 3/100



DAYA BAY
CONTAINMENT SCHEDULE

	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42
CONCRETE															
- Raft															
- Cylinder															
- Crown															
- Central Part															
LINER															
- Bottom plates and frustum															
- Cylinder															
- Prefabrication and erection of Dome															
- Welding of Dome															
PRESTRESSING															
- First stage V + H															
- Second stage V + H + Dome															
POLAR CRANE															
- Crane girders															
- Lifting of Polar Crane															