

THE CANDU 3 CONTAINMENT STRUCTURE



CA9800196

Introduction:

The design of the CANDU 3 nuclear power plant is being developed by AECL CANDU's Saskatchewan office. CANDU 3 rated at 450 MW of net electrical power output is a smaller and advanced version of the successfully operating CANDU plants. There are 24 CANDU nuclear power plant units operating in Canada and abroad and eight units are under construction in Romania and South Korea. The design of the CANDU 3 plant has evolved on the basis of the proven CANDU design. The experiences gained during construction, commissioning and operation of the existing CANDU plants are considered in the design. Many technological enhancements have been implemented in the design processes in all areas. The object has been to develop an improved reactor design that is suitable for the current and the future markets worldwide.

The existing design of CANDU containment structure is low pressure design with epoxy liner. It can be constructed reasonably fast and relieves overpressures gracefully. For such containments, alternative liners can be applied to improve leak tightness or fibre reinforced concrete can be used for future designs. Benefits of even faster construction schedule and simplification of designs leads to higher design pressure containment concept for CANDU 3. The use of steel liner is needed for the higher design pressure, further reduction of leak rate and the steel liner can be used as formwork during construction for further reduction of construction schedule.

Throughout the design phase of CANDU 3, emphasis has been placed in reducing the cost and construction schedule of the plant. This has been achieved by implementing design improvements and using new construction techniques. Appropriate changes and improvements to the design to suit new requirements are also adopted. In CANDU plants, the containment structure acts as an ultimate barrier against the leakage of radioactive substances during normal operations and postulated accident conditions. The concept of the structural design of the containment structure has been examined in considerable detail. This has resulted in development of a new conceptual design for the containment structure for CANDU 3. This paper deals with this new design of the containment structure.

Functions of Containment Structure:

The main function of the containment structure is to provide a leak tight enclosure for the reactor and associated equipment and systems. In addition to acting as a leak tight barrier, the thick concrete wall of the containment structure acts as a shielding wall and protects personnel from radiation. The containment structure houses and protects the reactor, fuelling machine, heat transport systems, equipment and various systems in the reactor building from environmental hazards such as the earthquake, wind and rainfall. The concrete walls of the containment are

designed to stop tornado generated missiles. The containment structure is capable of sustaining internal pressures due to postulated accident conditions without the need of water sprays. It also supports a variety of operational loads and is designed to withstand the effects of earthquakes. It is also necessary that the construction of the containment structure be integrated with the modular scheme of plant construction.

Containment Structure Concept:

The containment structure constitutes the outer boundary of the CANDU 3 reactor building. It consists of a thick perimeter wall in the shape of a cylinder founded on a circular base slab at the bottom and topped by a dome in the shape of a tori-sphere. The configuration of the containment structure is shown in Figure 1, which gives a cross-section through the reactor building. The containment structure is designed and constructed using reinforced concrete. In reinforced concrete structures, steel reinforcing bars are placed in the formwork before placing concrete. There is a steel liner located at the inner surface. The steel liner is used to obtain the leak tightness of the containment structure. The liner is supported with the use of embedments from the concrete wall. The steel liner also acts as a formwork during placement of concrete. The liner for the perimeter wall is welded to the liner at the base slab and to the inner surface of the dome so as to form a continuous barrier. In the base slab the liner is placed after completion of concreting. A layer of concrete will be placed on top of the liner in the base slab for protection. The dome liner also acts as the formwork for placement of concrete.

CANDU 3 containment structure is about 41 m in diameter and 47 meter in height. A change in the design philosophy has eliminated the need for the dousing tank and the dousing system located near the top of the reactor building of the CANDU 6. This reduces the height requirement of the containment structure.

Structural Design Aspects:

Reinforced concrete is selected as the material for the construction of the containment structure. Reinforced concrete is very versatile and common structural materials used in all forms of civil construction. The long history of design, testing and experience from actual use of such structures are available. This provides necessary assurance of the strength and durability of such form of construction. Reinforced concrete has been widely used for construction of containment structures in different parts of the world. Reinforced concrete structure is permeable and it is very normal to have small hairline cracks due to tension. To eliminate the permeability of concrete a liner is necessary. In the CANDU 6, the containment structure is made of prestressed concrete. A system of postensioning with cables is used. The use of prestressed concrete eliminated tensile stresses at the inside face and thereby reduced the potential of cracking. As a result, an application of an epoxy liner is used. The postensioning however involves added complexity in the design and construction requiring additional cost. In the CANDU 3 design concept, a reinforced concrete structure with the steel liner is used to provide the leak tight barrier. The materials and structural design of the containment structure must conform to the Canadian standards (References 1 and 2).

Containment Liner:

For CANDU 3, steel plates are used to form the liner in the inside surface of the containment structure. The steel liner is attached to the concrete surface using designed embedments and anchors. The materials used for fabrication of this liner follow the requirements in the CSA standard (Ref. 1). The concept of the liner for CANDU 3 is different from other existing plants where epoxy coating has been used. The use of a steel liner provides advantages in constructing the containment structure in a relatively shorter time period.

Construction Schedule:

The reduction of the construction schedule played an important role in determining the conceptual design of the CANDU 3 plant. The design concept is selected such that the construction schedule can be substantially reduced compared with previous CANDU plants. In CANDU 3 plant, the open top concept of construction has been adopted. The use of open top concept together with modularization is used to reduced the construction and installation time considerably.

The method and sequence of construction for the containment structure for CANDU 3 is different from previous plants. The perimeter wall will be constructed using the jump form technique in segments of several meters in height. The liner for the perimeter wall will be acting as the inner formwork for placement of concrete. The external form will be advanced upwards in sequence until construction of the wall is completed. In CANDU 3 the open top construction method will be used. In this method, the top of the containment structure will be kept open for installation of modules and equipment. Major equipment and modules are placed in the reactor building using a very heavy lift (VHL) crane through the opening in the top. After installation of all equipment, modules and structural steel the dome is closed to complete the containment structure. The scheme of installation of modules through the top of the containment structure is shown in Figure 2. In existing CANDU 6 plants the perimeter wall is slipformed taking about three weeks of around the clock operation. After that, the dome is constructed. Temporary openings are kept in the perimeter wall to bring in the materials for construction of the internal structure and installation of equipment. After completion of the work the temporary openings are closed. The installation of equipment through the construction openings created many constraints in the erection and installation works at the site. This concept has required a construction schedule of 60 months or more from the first concrete to in-service. This can be reduced by up to 12 months for new CANDU 6 plants by incorporating "open top" construction.

The use of modularization is a major factor contributing to a short construction schedule; 38 months from the first concrete to in-service for the first unit and for subsequent units 36 months. Modular construction also requires that construction of modules and manufacturing of major equipment must start before the first concrete date. In that way, many activities can be carried out at the site in a parallel mode instead of a series mode. As a result, less numbers of site crew will be working inside the reactor building at any time.

Pressure and Leakage consideration:

CANDU 3 containment structure is designed for a much higher pressures than the CANDU 6 , largely due to elimination of dousing. The design pressure due to LOCA without ECC of 230 kPa(g) is about 1.9 times higher than that for CANDU 6. At this design pressure the structural integrity and leak tightness will have to be maintained. Additionally the containment structure maintains its structural integrity during the steam main break condition.

For CANDU 3 the steel liner is considered to be a superior form of barrier. It is expected to provide a higher degree of leak-tightness with increased reliability over epoxy. It is also expected to be immune from degradation and aging will requiring maintenance and rework. As a result a lower leakage rate is expected for CANDU 3 containment structure. The containment structure will be subjected to the inaugural proof pressure and leakage testing according to Canadian standard (Reference 2).

Maintenance Consideration:

CANDU 3 plant is designed for a design life of 100 years. Therefore, provisions are made to replace components whose design life is less than 100 years. One of the major components that may need replacement is the steam generator. To replace the steam generator it will be necessary to cut holes in the top of the dome during a planned outage; the steam generator would then be exchanged using a VHL crane. After replacement the hole will be closed. This aspect of steam generator replacement has been considered in the concept of the containment structure. The use of reinforced concrete as the construction material provides this flexibility to cut holes in the structure and reconstruct at a later time.

Advantages of the CANDU 3 Design:

The current design for the CANDU 3 has the following advantages:

- (a) Similar concept has been successfully used for other power plants in the USA, Japan and Europe. Consequently information is available from experience in other plants which can be utilized.
- (b) The concept is economically attractive. Cost comparisons show a lower effective cost over other alternative concepts that have been evaluated.
- (c) The design is integrated with the project objective of reducing the construction schedule and is well coordinated with the modular open top construction scheme. This results in reduction of the total project cost.

(d) The design and construction efforts will be less for reinforced concrete compared with prestressed concrete. Prestressed concrete design involve additional complexity. Moreover selection of the vendor for the prestressing system affects the design details. Construction of prestressed concrete requires additional materials and more number of operations are necessary. This also eliminates inspection and retensioning requirements for post tensioning cables - likely a requirement for new plants.

(e) The containment is expected to exhibit superior leak-tight performance and be less susceptible to degradation due to aging.

CADD Modelling Consideration:

In the recent years there have been dramatic advancements in the CADD design area due to use of powerful computers and software. The design of CANDU 3 takes full advantage of the currently available technology in design work. CADD's three dimensional modelling capability has been utilised in creating the graphic model of the whole plant. Project data resides in an integrated data base which is kept updated and accessed by users in different disciplines. The same data can be transferred to various analysis and design software avoiding manual interfacing. Using software intelligence, interferences can be detected early and corrected. This is likely to generate designs having more uniformity and less inconsistency of technical information.

Analysis and Design:

Canadian standards for the concrete containment structure (Reference 3) are used for design and analysis works. Analysis is done using the finite element based computer programs which needs the use of high performance computers. The structural design of the containment structure requires repetitive calculations which can be effectively programmed. Specially developed design software are used for the design of the containment structure. The simulation of the containment structure commonly called the analysis model will be created using the integrated database for the CADD's graphic model.

Three dimensional finite element models of the containment structure using plate elements have been created for the containment structure using the ANSYS computer program. Such models have be analyzed for postulated loading conditions. In addition to normal operating loads severe loads during postulated accident condition or environmental conditions are considered. Such analyses have provided assurance of the validity of the concept. The finite element model for the containment structure showing the airlock opening used for stress analysis is shown in Figure 3.

Conclusions:

The CANDU 3 containment structure is an advancement in the concept and possess superior design features. The concept is economic and provides necessary protection against normal and abnormal loads. Construction of such structure has been integrated in an efficient construction schedule using the open top construction approach. Such containment structure has been standardised for CANDU 3. Further evolutionary concepts to incorporate passive heat sink concepts are being developed for future CANDU plants.

References:

1. Canadian Standard N287.2, Materials Requirements of Concrete Containment Structure for CANDU Nuclear Power Plants
2. Canadian Standard N287.3, Design Requirements for Concrete Containment Structure for CANDU Nuclear Power Plants
3. Canadian Standard N287.6, Pre-operational Proof and Leakage Rate Testing for Concrete Containment Structure for CANDU Nuclear Power Plants

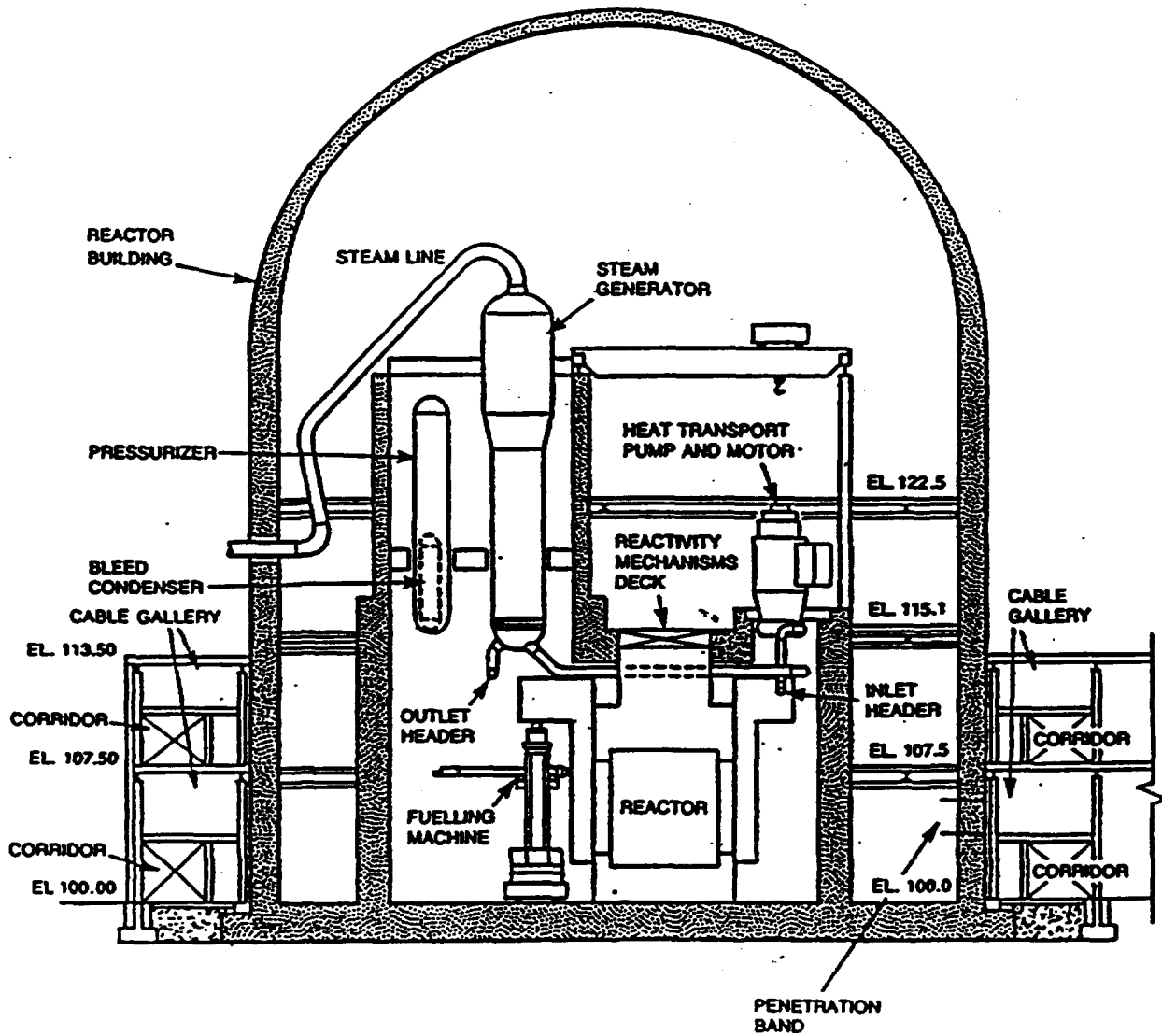


FIGURE 1 REACTOR BUILDING SECTION

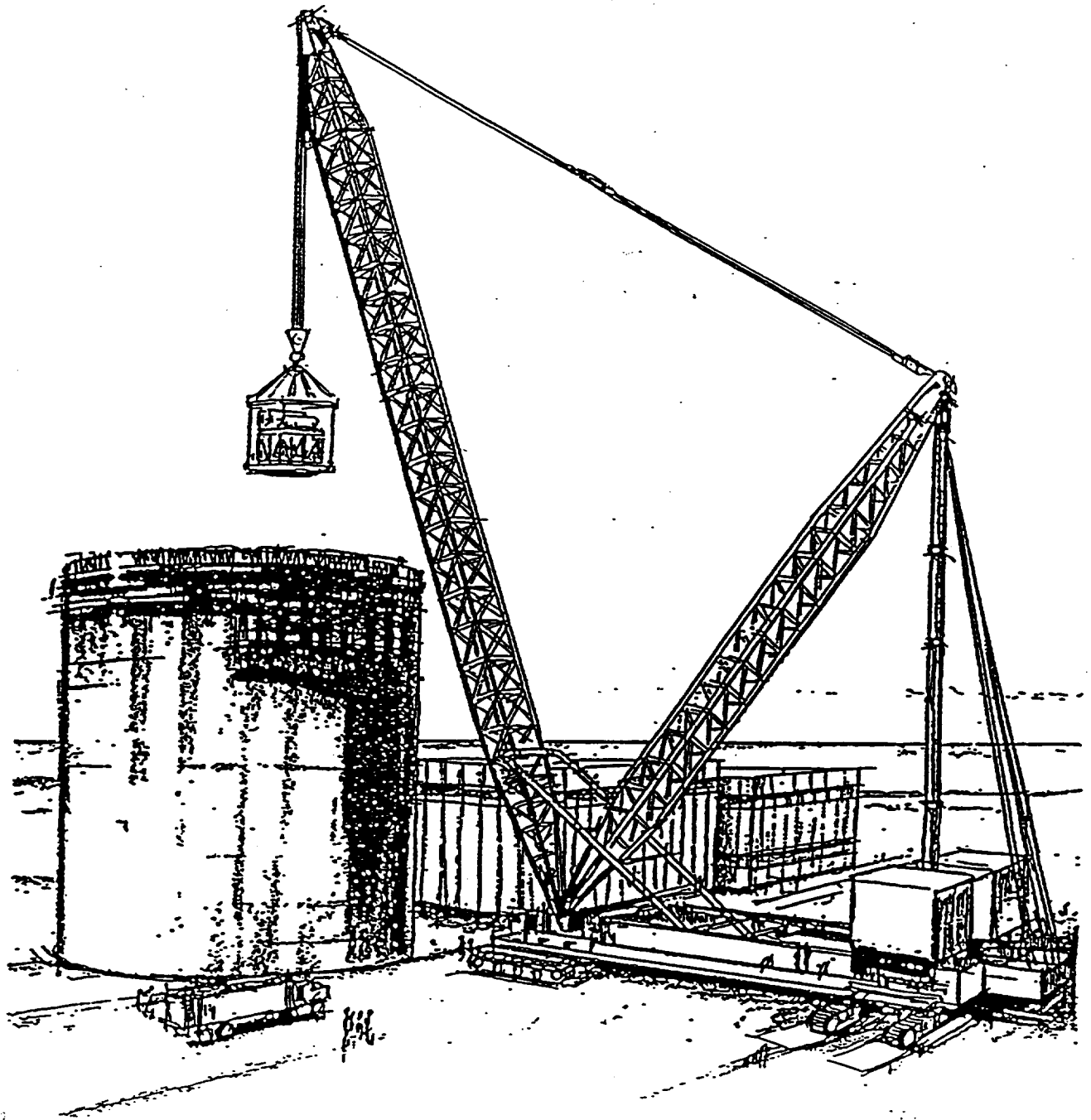


FIGURE 2 MODULE PLACEMENT WITH VHL CRANE

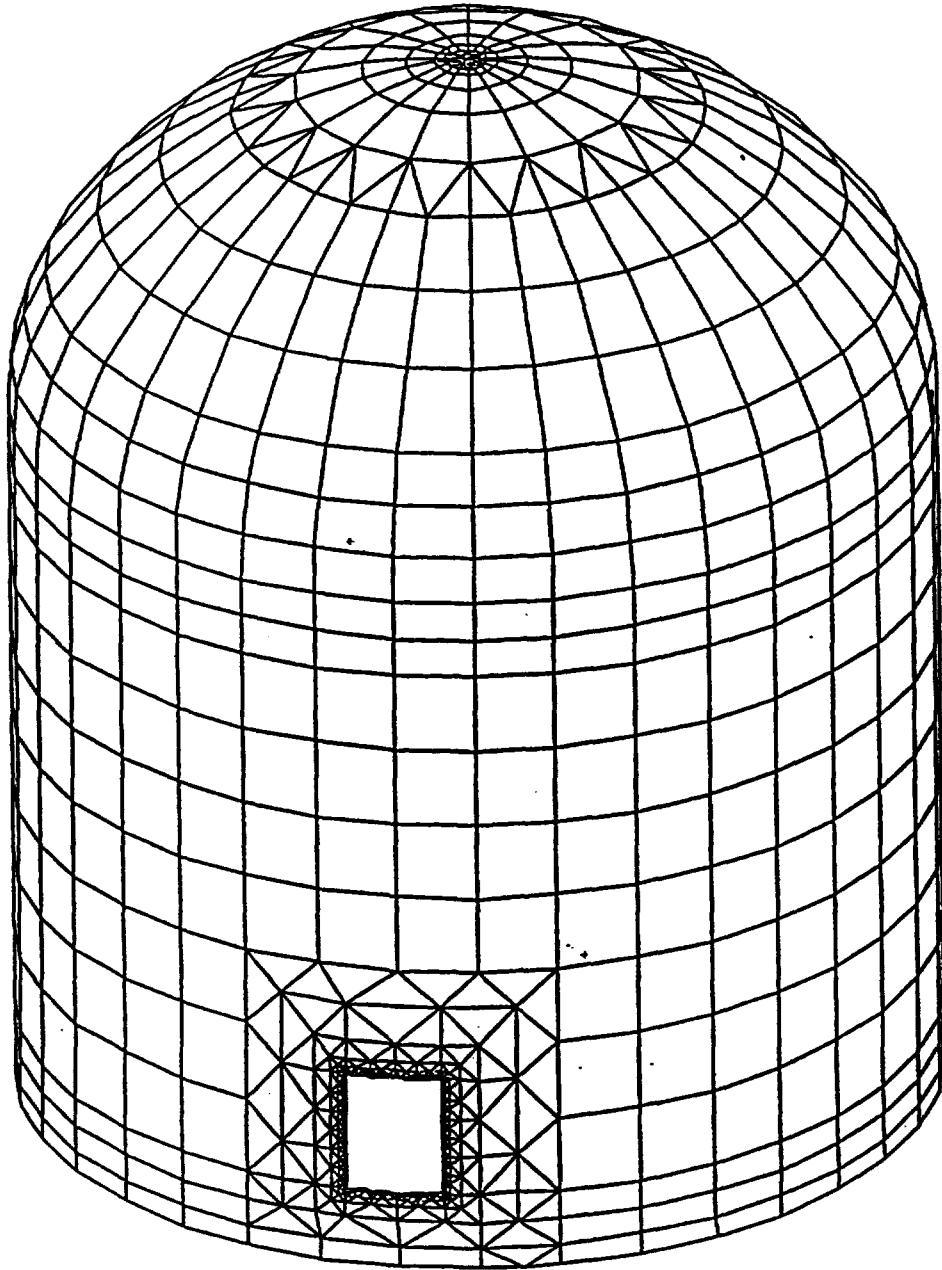


FIGURE 3 ANALYSIS MODEL OF THE CONTAINMENT STRUCTURE