APPENDIX 5C

DESIGN CRITERIA FOR REACTOR BUILDING

1 GENERAL

The prestressed concrete Reactor Building will be designed to have a low stra elastic response to all conceivable loads, thereby ensuring that the integrit of the vapor barrier is never breeched. The intent of the design is also to provide a mode of failure should the vessel ever be tested to destruction of ductile rather than a brittle manner. The design will be further based upon various combinations of factored loads that are based upon factors by which loads are increased to approach the limit of an elastic response. These factors are developed in a similar manner to the Ultimate Strength Design pro visions of ACI 318-63 where factors are applied for those factors outlined in the "Commentary on Building Code Requirements for Reinforced Concrete," ACI 318-63.

In the case of this design wherein a more exact analysis is performed than contemplated by ACI 318, the load factors primarily provide for a safety margin on the applied loads. The Reactor Building will be analyzed to ensure proper performance of all components including the liner, concrete shell, and reinforcement under the following loading conditions:

a. During construction but prior to prestressing

b. During prestressing

c. At normal operating conditions

d. At test conditions

e. At factored loads

2 METHOD OF ANALYSIS

GENERAL

The shell of the Reactor Building will be analyzed to determine all stresses, moments, shears, and deflections due to the static and dynamic loads listed in Section 1.2, Appendix 5B, of the original PSAR.

STATIC SOLUTION

The static load stresses and deflections that are in a thin, elastic shell of revolution are calculated by an exact numerical solution of the general bending theory of shells. This analysis employs the differential equations derived by E. Reissner and published in the "American Journal of Mathematics, Vol. 63, 1941, pp. 177-184. These equations are generally accepted as the standard ones for the analysis of thin shells of revolution. The equations given by E. Reissner are based on the linear theory of elasticity, and they take into account the bending as well as the membrane action of the shell.

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he method of solution is the multisegment method of direct integration, which s capable of calculating the exact solution of an arbitrary thin, elastic hell of revolution when subjected to any given edge, surface, and temperature oads. This method of analysis was published in the "Journal of Applied echanics," Vol. 31, 1964, pp. 467-476 and has found wide application by many ngineers concerned with the analysis of thin shells of revolution. 2

he actual calculation of the stresses produced in the shell and foundation as carried out by means of a computer program written by Professor A. Kalnins f Lehigh University, Bethlehem, Pennsylvania. This computer program makes se of the exact equations given by E. Reissner, and solves them by means of he multisegment method mentioned above. The program can solve up to four ayers in a shell and these layers can have different elastic and thermal roperties and can vary in thickness in the meridional direction. Applied loads an vary in meridional and circumferential directions.

YNAMIC SOLUTION

he stresses and displacements of the response of a shell of revolution to the xcitation of an earthquake can be calculated by superimposing the normal odes of free-vibration of the shell. The modes of vibration are calculated y means of the general bending theory of shells derived by E. Reissner. The ranslatory inertia terms in the normal, meridional, and circumferential irection of the shell are taken into account. The mass distribution is the ctual mass distribution of the shell and no approximations are made. E. eissner's shell theory is such that it predicts exactly the complete spectrum f natural frequencies of the shell without any approximations.

he differential equations given by E. Reissner are solved by means of the ultisegment direct integration method of solving eigenvalue problems, which as published by A. Kalnins in the "Journal of the Acoustical Society of merica," Vol. 36, 1964, pp. 1355-1365. According to this method, the igenvalue problem of a shell of revolution is reduced to the solution of a requency equation which vanishes at a natural frequency. The frequency quation consists of exact solutions of E. Reissner's equations, and no pproximations are made.

he calculation of the natural frequencies and the corresponding mode shapes f each mode of free-vibration is performed by means of a computer program ritten by A. Kalnins. The computer program has been used for the calculation f the dynamic characteristics of many types of shells of revolution and its esults have been verified with experiments on many occasions (a listing of revious applications is attached). The program calculates the natural requencies of any rotationally symmetric thin shell within a given frequency nterval and gives all the stresses, stress-corresponding to a natural requency, consultants and displacements at any prescribed point on the eridian of the shell.

he normal modes of free-vibration need only be added in order to construct he response of the shell to an earthquake. The relationship between free-ibration and a given excitation is given by the following equation:

$$Y(x,t) = \sum_{i=1}^{N} Yi(x) \frac{Ci\ Svi}{Wi\ Ni}$$

where $Y_{(x,t)}$ = fundamental variables of the response

$Yi\ (x)$ = fundamental variables of the i^{th} mode

Wi = natural frequency of the i^{th} mode

Ni = constant for the i^{th} mode

Svi = maximum velocity from the response spectrum for a single degree of freedom system for a given value of Wi for the i^{th} mode

For analysis purposes the Reactor Building shell is divided into structural parts, and each part is divided into a specified number of segments.

The Static Analysis and Dynamic Analysis have been used by the following companies for the analysis of thin shells:

1. Martin Company - Orlando, Florida
2. Pratt and Whitney - Aircraft, East Hartford, Conn.
3. Central Electricity Generating Board - London, England

The Static Analysis has been evaluated by H. Kraus, in Welding Research Council Bulletin, No. 108, September 1965.

The Dynamic Analysis has described and its results compared to experiment by:

J. J. Williams, "Natural Drought Cooling Towers - Ferry bridge and after," in the Institution of Civil Engineers publication, 12 June 1967.

The nonaxisymmetric loads imposed upon the Reactor Building base slab will not have a contributing influence upon the design of the shell; therefore, the foundation slab will be designed for nonaxisymmetric loads by considering a circular slab on an elastic foundation.

3 LOADING STAGES

3.1 DURING CONSTRUCTION BUT PRIOR TO PRESTRESSING

The Reactor Building will be designed as a conventional reinforced concrete structure subjected to dead, live, wind, and construction loads with allowable stresses in accordance with the limits established by ACI 318-63.

3.2 DURING PRESTRESSING

The Reactor Building will be designed for prestress loads and will be checked to insure that the concrete stress will not exceed .6f'c at initial transfer.

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Stresses due to shrinkage, creep, and elastic shortening of concrete will be taken into account, and flexural creep tending to relieve bending stresses will also be considered. All remaining stresses will be in accordance with ACI 318-63, Chapter 26.

3.3 AT NORMAL OPERATING CONDITIONS

The loads due to normal operating conditions are:

a. External pressure of 2.5 psig

b. Operating temperature transients

c. Dead load

d. Live load

e. Prestress load

f. Seismic load

g. Snow and wind load

The stresses in the concrete and reinforcing steel resulting from these loads will be in accordance with ACI 318-63, Chapter 26. The stresses and strains will be such that the integrity of the liner will be maintained.

3.4 TEST LOADS

The Reactor Building will be designed to function under the following loads at test conditions:

a. Internal pressure of 1.15 times accident pressure

b. Dead load

c. Live load

d. Prestress load

e. Temperature transients at test conditions

The allowable stresses will be in accordance with ACI 318-63 Chapter 12 and 26

The vessel will be adequately instrumented to verify during the pressure test that the structural response of the principal strength elements is consistent with the design.

3.5 AT FACTORED LOADS

The building will be checked for the factored loads and load combination given in Appendix 5A, and compared with the yield strength of the structure. The load capacity of the structure is defined for our design, as the upper limit of elastic behavior of the effective load carrying structural materials.

For steels, (both prestressed and non-prestressed) this limit is considered to be the guaranteed minimum yield strength. For concrete, the yield strength is limited by the ultimate values of shear (as a measure of diagonal tension) and bond per ACI 318-63, and the 28 day ultimate compressive strength for flexure (f'c). A further definition of "load capacity" is that deformation of the structure which will not cause compressive strain in the steel liner plate to exceed 0.005 in/in, nor average tensile strains to exceed that corresponding to the minimum yield stress.

The load capacity of all load carrying structural elements will be reduced by a capacity reduction factor ($\emptyset$) as stated in the basic structural design criteria. This factor will provide for "the possibility that small adverse variations in material strengths, workmanship, dimensions, control, and degree of supervision while individually within required tolerances and the limits of good practice, occasionally may combine to result in under-capacity" (refer ACI 318-63, p.66 - footnote).

The allowable tensile capacity of concrete for membrane stresses (i.e., excluding all flexural and thermal stresses) due to the factored loads will be $3\sqrt{f'c}$. The allowable tensile capacity of concrete for maximum fiber stresses to the factored loads including the thermal load plus other secondary effects will be $6\sqrt{f'c}$. Where tensile fiber stresses exceed the allowable, mild steel reinforcement will be added on the basis of cracked-section design. The addition of mild steel reinforcement and the increase in steel stress will be determined in a manner similar to that contained in ACI 505-54 "Specification for the Design and Construction of Reinforced Concrete Chimneys." The minimum steel on the exposed face of the concrete will be 0.15 percent of the cross-sectional area of the concrete as indicated in Paragraph 15 of Appendix 5B to the PSAR.

The cracking limit of the concrete in principal tension will be governed by the allowable values of the shear as a measure of diagonal (principal) tension. The allowable shear values will be as follows:

a. When membrane tension exists or when membrane compression is less than 100 psi, the section will be designed to the ultimate shear provisions of Chapter 17 of the ACI Code 318-63. Where shear reinforcement is required sufficient prestressed force will be provided so that the net membrane force remains in compression or zero tension so as to result in a condition analagous to that covered in Chapter 17.

b. When membrane compression of greater than 100 psi exists, the principal membrane tension will be limited by the ultimate shear provision of Chapter 26 of the ACI Code 318-63.

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