Comparative Study of Two and Three Buttress Systems for KNGR Containment Hoop Tendons

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ABSTRACT

The containment of the Korean Next Generation Reactor(KNGR) is a prestressed concrete shell consisting of a cylindrical wall and hemi-spherical dome, and is founded on a rectangular common basemat for both containment and auxiliary buildings.

The buttresses around the perimeter of the containment are used to provide anchorage for the hoop tendons. The number and location of these buttresses will influence the containment behavior as well as containment cost and construction schedule. This study is to examine the use of two and three buttress systems for anchorage of hoop tendons, and to compare the advantages and disadvantages associated with two and three buttress systems for the KNGR containment.

INTRODUCTION

The reactor containment has always been regarded as an important engineered safeguard because it is the final barrier to protect the public against the release of radioactive substances to the atmosphere in the event of an accident. KNGR containment system is designed for the effects of licensing design basis accidents, such as LOCA and main steam line break(MSLB), but also to prevent the occurrence of a severe accident and to mitigate and robustly withstand the consequences of a severe accident with ample design margin.

The recent containments in Korea have typically utilized the three buttress system for anchoring hoop tendons. In the three buttress system, the buttresses are spaced 120° apart and each hoop tendon spans 240° bypassing the intermediate buttress. Thus, three tendons form two complete rings. With the two buttress system, the tendons will span 360°. Thus, each tendon forms one complete ring resulting in:

- a wider spacing of tendons for the same equivalent hoop compression as the three buttress containment, or
- a larger hoop compression with the same tendon spacing as the three buttress containment.

The KNGR containment is designed to operate with a design life of 60 years, and a design pressure of 60 psig, severe accident pressure of 115 psig, and containment inner diameter of 150 feet, which requires greater post tensioning than existing containments in Korea. For this reason, a comparative study of two and three buttress systems for containment hoop tendons is performed to investigate the feasibility of using two buttress system instead of three buttress system which has been commonly used in Korean existing containments.

KNGR CONTAINMENT DESCRIPTION

The KNGR containment is a prestressed concrete shell composed of a right cylindrical wall and a hemispherical dome founded on a nuclear island common basemat as shown in Figure 1. The entire surface of the containment is lined with steel plate that serves as a leak-tight membrane. The concrete shell and dome are prestressed using a post-tensioning system consisting of horizontal hoop tendons and vertical inverted-U tendons.

The KNGR containment size and design pressure for optimal cost are evaluated as follows:

- internal diameter : 150'-0"
- free volume : 3.13x10^6 ft^3
- springline height : 176'-6"
- design pressure : 60 psig

There are several post-tensioning systems available for providing the required prestress in the containment concrete. 1,000 ton capacity of post-tensioning system such as VSL E5-55 has been used in the recent containments in Korea, which is the basis of the KNGR containment post tensioning system. Hoop prestress of the cylindrical wall is provided by 165 hoop tendons at 12 inch spacing starting from El. 90'-6"(12'-6" above top of basemat) with three buttress system as a basis. Vertical prestress of the cylindrical wall is provided by two sets of 50 orthogonal inverted-U tendons.

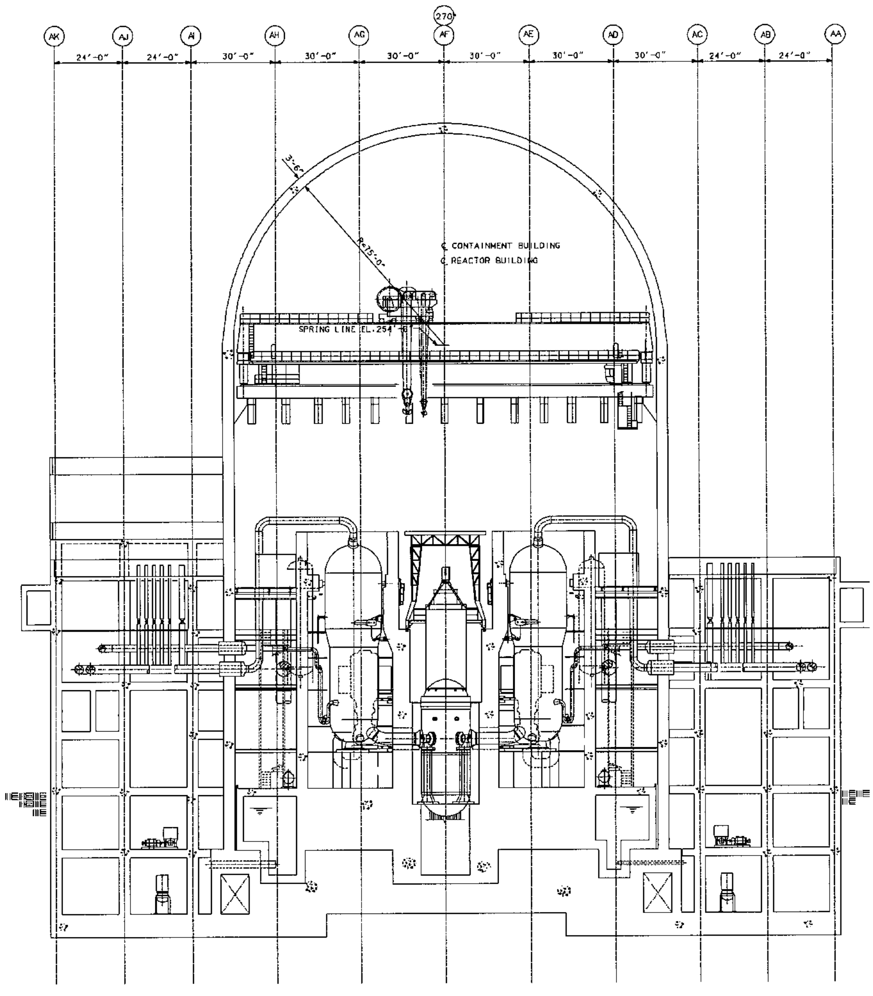

Figure 1 General Arrangement of KNGR Nuclear Island

COMPARATIVE STUDY

This study is based on the following KNGR containment geometric and design parameters:

- Hoop tendons at a radius : R = 78 feet
- Ultimate tendon strength(f_{pu}) : f_{pu} = 270 ksi
- Wobble friction coefficient(μ) : μ = 0.0003
- Curvature friction coefficient(κ) : κ = 0.14
- Tendon relaxation(γ) : γ = 6% at 0.7 f_{pu}

The values of 60-year prestress loss will be larger those for the typical 40-year plant life used in the current operating plants, and time-dependent losses of prestress in post-tensioning tendons are accounted to calculate the effective prestress with use of low-relaxation strand to minimize the effect.

To compare the advantages and disadvantages associated with two and three buttress systems, items such as variations in hoop tendon prestress, ovaling effect, constructibility, cost comparison for tendon installation/in-service inspection, and design flexibility are evaluated.

Variation in Hoop Tendon Prestress

The total losses in hoop tendons are composed of short term and long term losses due to anchor slippage, concrete elastic shortening, concrete creep, concrete shrinkage, and tendon relaxation. And the final effective hoop prestress along the perimeter of the containment wall is calculated considering the tolerance band based on the requirements of Reg. Guide 1.35.1.

Figure 2 and 3 show the variation of prestress along a hoop tendon, and the results are as noted in Table 1. The variation of prestress along the perimeter of the containment wall is as shown on Figure 4 and 5 for three and two buttress system respectively.

As shown in Figures 2 thru. 5, variation in hoop tendon prestress is larger for the two buttress system, however, variation of average stress around the circumference in the tendon system is small and similar between the two systems. And both systems are considered applicable to the KNGR containment with approximately 10% more tendons in overall length for the two buttress system.

Table 1 Variation of Prestress Along a Hoop Tendon

No. of buttresses	Location of effective stresses	- Initial stresses	- Final stresses
Three buttress system(Figure 2)	- At anchor point	189.0 ksi	132.5 ksi
	- At tangent point	202.5 ksi	146.0 ksi
	- At mid point of hoop tendon	156.7 ksi	100.2 ksi
	- Average tendon stress	183.4 ksi	126.9 ksi
Two buttress system(Figure 3)	- At anchor point	189.0 ksi	127.5 ksi
	- At tangent point	202.5 ksi	141.0 ksi
	- At mid point of hoop tendon	132.1 ksi	70.6 ksi
	- Average tendon stress	172.2 ksi	110.7 ksi

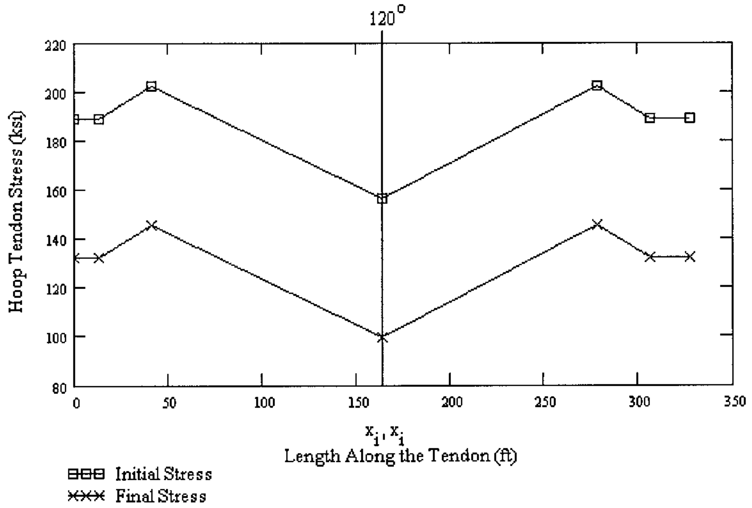

Figure 2 Variation of prestress along a hoop tendon for three buttress system

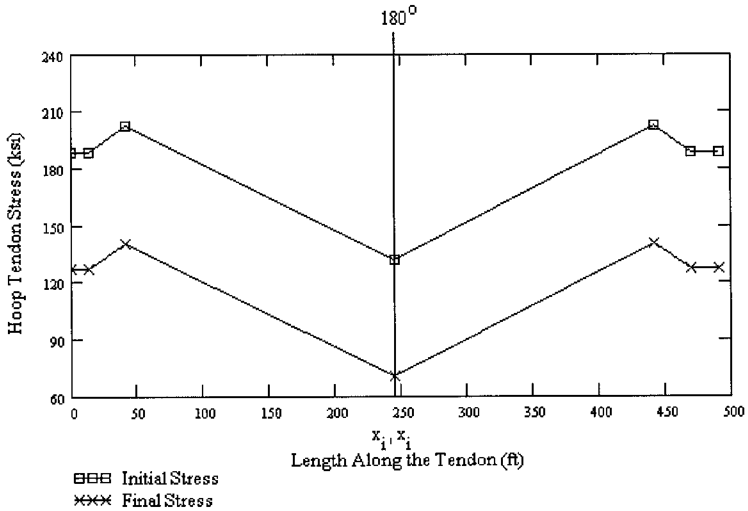

Figure 3 Variation of prestress along a hoop tendon for two buttress system

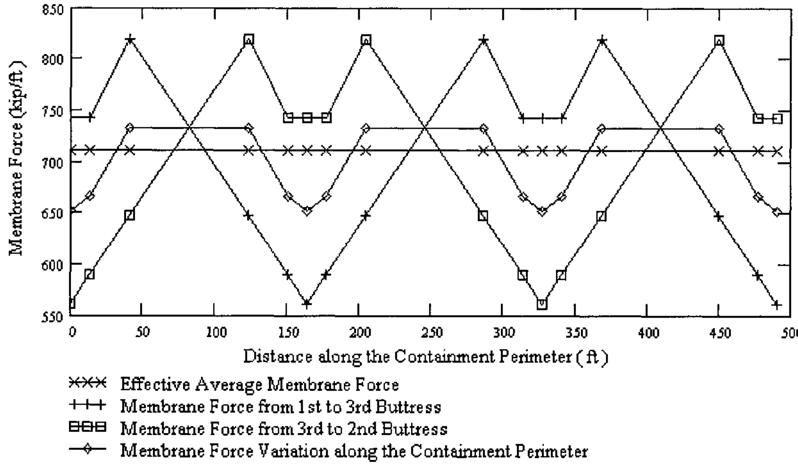

Figure 4 Variation of prestress along the perimeter of containment wall for three buttress system

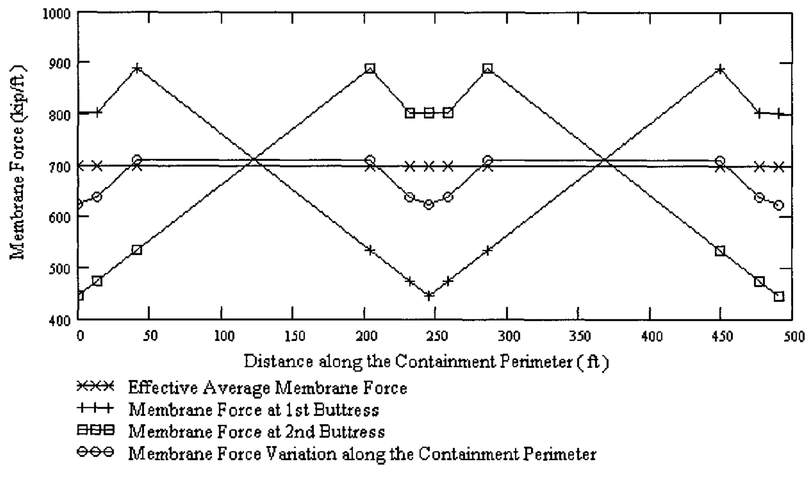

Figure 5 Variation of prestress along the perimeter of containment wall for two buttress system

Ovaling Effect

In both the two and three buttress systems, due to the radial deflection forces resulting from the deflection of hoop tendons at the buttresses, the containment will be subjected to horizontal forces at the buttress locations which are directed toward the containment center. For the three buttress system, these forces are applied at AZ. 0°, 120°, and 240°. For the two buttress system, the deflection forces are only applied at AZ. 0° and 180°. Therefore, the ovaling effect for the two buttress system is more pronounced than that for the three buttress system. However, this ovaling effect will have no significant impact on containment design considering the concrete thickness of 4 ft. and 3.5 ft for the cylinder wall and dome, respectively.

Constructibility

In comparison to the three buttress system, the two buttress system has larger tendon spacing which is desirable since it reduces congestion at deflection points around major penetrations. The buttresses can also be aligned with the dome orthogonal reinforcing pattern, eliminating the necessity of special rebar detailing at points where the dome tendons pass through the outside face reinforcing. The elimination of one buttress also reduce the exclusion zones on the inside surface of the containment, and this allows more freedom to locate mechanical, electrical, and instrumentation penetration sleeves. These exclusion zones are required so that penetrating items passing through the containment shell do not interface with movement of the post-tensioning work platforms which ride up and down along both sides of the buttresses, and minimum space requirement considering the installing radius of the curved tendon.

Cost Comparison for Tendon Installation/In-service Inspection

According to the calculations for determining the maximum spacing for the hoop tendons of the three and two-buttress system, hoop tendons at a 12 inch and 16 inch spacing will be adequate for a design pressure of 60 psig, respectively.

The total hoop tendon length for the three buttress system is approximately 65,700 feet requiring a total of 390 tendon anchors and anchor bearing plates. The total hoop tendon length for the two buttress system is approximately 73,100 feet requiring a total of 294 tendon anchors and anchor bearing plates. Therefore, for the two buttress system, the hoop tendon cost will be increased than three buttress system. In addition, for the two buttress system, special tendon anchor pockets which require skilled labor will increase the cost.

In-service inspection requirements of un-grouted tendons in prestressed concrete containments are provided in USNRC Regulatory Guide 1.35. Per position 1 of this Reg. Guide, the in-service inspection should be performed 1, 3, and 5 years after the initial structural integrity test (SIT) and every 5 years thereafter. The ISI cost for the two-buttress system will be marginally less than that for the three-buttress system. Table 2 shows those requirements which depend on the number of hoop tendons resulting from the use of three and two buttress system. As discussed above the ISI cost for the two buttress system will be marginally less than that for the three buttress system because the majority of the ISI cost is associated with the equipment and contractor mobilization.

According to the detailed comparison considering the above discussions, the cost for two buttress system is estimated to be slightly higher than that for the three buttress system.

Table 2 Number of Hoop Tendon Samples for ISI

ISI Period	Selected Tendon No.(%)	Selected Minimum Tendon No.	Selected Maximum Tendon No.	Selected Tendon No.	
				Two buttress	Three buttress
1 year	4 %	4	10	6	8
3 years	4 %	4	10	6	8
5 years	4 %	4	10	6	8
10,15...60 years	2 %	3	5	3	4

Design flexibility

All post-tensioning systems utilize approximately 6-inch diameter sheathing embedded in concrete to provide a passage duct for installing and stressing the post-tensioning tendons after the concrete construction of the containment shell is complete. Construction problems will arise if the tendon spacing is too close, therefore, a minimum tendon spacing of 12 inches is prescribed as a constructibility requirement for this study.

According to the structural analysis of the containment structure for the three buttress system, maximum design pressure capacity is calculated to be 60 psig, whereas containment design pressure capacity can be increased to about 80 psig for the two buttress system when the spacing of horizontal tendon is narrowed to 1 ft. However, compressive strength of the concrete should be increased accordingly.

CONCLUSIONS

Based on the comparisons presented in this study, the following conclusions indicating major merits of both systems can be made:

- For an variation in hoop tendon prestress and the ovaling effect, the three buttress system is superior, however, the two buttress system is also acceptable.
- From a constructibility standpoint, the two buttress system is superior since it reduces tendon congestion at deflection points of large penetrations, and facilitates ease of dome rebar detailing/placement.
- From a cost standpoint considering both tendon system installation and ISI, the three buttress system will be slightly less costly.
- From a design flexibility standpoint, the two buttress system can be designed with an increased design pressure without impacting the constructibility when the compressive strength of the concrete is increased accordingly.

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