

**Study on Minimization of Weld Deformation for Core Shroud  
by Application of Design Optimization Technique**

J. G. Kim, K. W. Park, J. S. Moon, Y. H. Cho and J. H. Bae

Korea Power Engineering Company, Inc  
150 Dukjin-dong, Yusong-gu, Taejon, Korea 305-353

**Abstract**

Core shroud is fabricated by thin steel plates to minimize a thermal effect due to neutron irradiation. By reason of this, the weld deformation occurred during manufacturing has been raised seriously since Palo Verde nuclear power plant.

In this study, a method to minimize the weld deformation is investigated by application of the optimization technique to core shroud design. For this purpose, variation of welding area and shift of reinforcement location are utilized to demonstrate the changes before and after optimization. The results show that the welding area on core shroud can be remarkably reduced by design optimization so that the weld deformation will be minimized.

**1. Introduction**

The core shroud (Fig. 1) is called for tight manufacturing tolerance in order to avoid the damage on fuel bundle and minimize the bypass flow in core region[1]. Since, however, the core shroud is fabricated by relatively thin and long vertical plates to minimize the thermal effect and made of stainless steel to prevent corrosion and embrittlement due to neutron irradiation, this structure is apt to be distorted often due to the weld deformation and therefore requires a sufficient manufacturing time to properly correct structural distortion occurred.

In this study, an application of optimization technique to core shroud is initially attempted to minimize the weld deformation. Moreover, the locations of core shroud reinforcement are optimized to ensure the structural integrity or its possibility of improvement. For the purpose of this, 2-D axisymmetric model is developed and optimization procedure is then established by employing various parameters in ANSYS[2]. Lastly, comparative studies are performed to show the optimization effects for Korean Standard Nuclear Power Plant (KSNP) and Korean Next Generation Reactor (KNGR), respectively.

## 2. Application of Optimization Technique [2,3,4]

### 2.1 Selection of Objective Component

To choose the component to be optimized, namely objective component, some candidates are considered with respect to the feasibility of design modification and availability of result and its impact on interfaces, etc. The core shroud consists of many components such as panel, top & bottom plates, rib & brace, ring and guide lug. Various discussions are carried out for these components as follows ;

#### *Panel & Ring*

Core shroud panel is thin vertical structure which is encircled by ring. Because the ring forms gap between core shroud and core support barrel as a path for bypass flow, the design change of these components may significantly affect the reactor vessel and thermal hydraulic design. Therefore it is reasonable that modification of these components are not appropriate in this study.

#### *Brace & Rib*

The brace and rib are reinforcement installed at the annulus space between panel and ring. These are easier to attempt the modification relatively than the components mentioned above. In addition, it is expected that design modification of these components has a weak influence on the other core shroud components or the interfaces and then they are useful to clearly demonstrate the optimization effect. For this reason, it is concluded that these are suitable for this study as a objective component.

### 2.2 Development of Optimization Model

Developing an appropriate model is very important toward realizing an design optimization. Hence, the model must represent reality in a simple but meaningful manner.

#### *Model Generation*

It is natural that the analysis results of existed 3-D model have higher accuracy than 2-D model's. On the other hand, it is also true that 3-D model has difficulty in being applied to this analysis due to some inconveniencies including model modification. In this study, accordingly the 2-D axisymmetric model is developed for KSNP and KNGR as shown in Fig. 6(a) and Fig. 7(a), respectively although its limitations on geometrical expression and computational accuracy. The use of 2-D axisymmetric model can greatly reduce the modeling and analysis time compared to equivalent 3-D model.

The detailed analysis result for the existed KSNP 3-D model[5] was used to assess the adequacy of 2-D model developed. In comparison with the critical stresses between two

models, the stress values of 2-D model show slightly higher than those of 3-D model. However, in consideration of the stress distribution and deformed shape, the 2-D model was found to be appropriate for the purpose of this study.

### *Geometrical Features*

As shown in Fig. 1, the model is generated on the basis of a middle section of core shroud which is 27" height including ring. Although it is assumed that all ribs are attached to the ring with fully welded along the whole interfaces and uniform depth, in the real world it is not true as shown in Fig. 2(a). Therefore, the beam element having a different height is used for ribs at these areas .

The corner section of core shroud panel has a thinner thickness (0.5") than the other section (0.875") because this is designed to minimize thermal effect and also to be easy for mechanically bending during fabrication as shown in Fig. 2(b). The beam element with a different thickness is also used for the corner areas to accommodate this geometrical feature.

### *Loading Condition*

From the experiences for the existed core shroud analysis[5,6], both the pressure and thermal loads are key factors for dominating the magnitude of stress. In this study, the pressure load is only considered to avoid complication of optimization study. For actual core shroud, internal pressure on the core shroud panel is linearly increased from the top to the bottom. In this study, it is assumed that internal pressure of 35 psi is uniformly distributed on the panel surface.

Thermal loading also may significantly affect the core shroud stress analysis and then this case has to be included for the better answer. However, this requires additional assumptions and complicated calculation procedure for its application, and therefore, it is concluded that thermal load case is not taken into account in this study.

## 2.3 Design Optimization using ANSYS

### *Optimization Parameters*

Optimization parameters used for this study are shown in Fig. 3. The ANSYS optimization method employs three types of variables that characterize the design problem. Design variables are independent variables and are subject to upper and lower limits which sometimes referred to as geometric constraints. The objective function and state variables are both dependent variables. State variables are also constrained by upper and lower limits, sometimes referred to as behavioral constraints. Following equations (1) thru (5) represent a optimization parameters used in this study ;

$$\text{Object Function : } f = \text{sum} (\text{hbra2a}, \text{hbra2b}, \text{hbra2c}, \text{hbra3a}, \text{hbra3b}, \text{hbra3c}) \quad (1)$$

$$\text{Design Variable : } 0 \leq n2y \leq 7.5 \text{ for KSNP} \quad (2)$$

$$8 \leq n3y \leq 20$$

$$22 \leq n9y \leq 35$$

$$22 \leq n10y \leq 33$$

$$54 \leq n31x \leq 58$$

$$0 \leq n2y \leq 7.5 \text{ for KNGR} \quad (3)$$

$$8 \leq n3y \leq 25$$

$$33 \leq n9y \leq 45$$

$$33 \leq n10y \leq 43$$

$$62.5 \leq n31x \leq 67$$

$$\text{State Variable : } -10000 \leq \text{Stress Bound} \leq +10000 \text{ for KSNP} \quad (4)$$

$$-15000 \leq \text{Stress Bound} \leq +15000 \text{ for KNGR} \quad (5)$$

Width of braces (hbra2a, hbra2b, hbra2c, hbra3a, hbra3b, hbra3c) and location of ribs (n2y, n3y, n9y) and braces (n10y, n31x) are selected to the design variable. The former are to derive the variation of welding area while the latter are to meet the loading condition as a constraint on this analysis. The state variables,  $\pm 10000$  psi for KSNP and  $\pm 15000$  psi for KNGR, are determined according to the existed analysis results[5,6] and engineering judgement. Sum of each brace width is selected to the objective function to find the variation of welding area by optimization.

#### *Optimization Tools*

The first order method is used for this design optimization. First-order method uses derivative information, i.e., gradients of the dependent variables with respect to the design variables. For each iteration, gradient calculations are performed to determine a search direction. Each iteration is composed of sub-iterations that include search direction and gradient computations. In other words, one first order optimization iteration will carry out several analysis loops.

### **3. Results & Discussion**

Fig. 4(a) and (b) show convergence process of objective function and state variables, respectively. Optimization results for KSNP and KNGR are summarized in Table 1. The initial values of design variables provided in Table 1 are determined on the basis of the core shroud drawings for KSNP[7] and KNGR[8].

#### *Variation of Welding Area*

By the application of design optimization, it is shown that the welding area of core shroud can be reduced approximate 40% and 30% comparing with their initial designs for KNGR,

respectively. Based on these results, it can be expected that the structural distortion can be minimized by proper modification of brace shape. Especially for hbra2a in Table 1, the result shows the distinguished width reduction after optimization for both KSNP and KNGR. This implies that current size of hbra2a is too conservative and hence this area has relatively a sufficient room for shape modification.

#### *Shift of Reinforcement*

The shift of reinforcement location before and after optimization is shown in Fig. 5. The optimized results for KSNP are very close to those of initial design at every rib locations, whereas KNGR case shows some of initial locations are greatly shifted after optimization. From these result, it is proved that the existed core shroud for KSNP has a stable and compact design with respect to structural integrity as shown in Fig. 6.

On the other hand, it is expected that the present KNGR core shroud has a possibility of the design improvement by relocation of rib or brace. These optimization effects for KNGR are visually shown in Fig. 7. In particular for the ribs at n3y and n9y, the results show that their maximum stresses can be significantly lowered by relocation of only these two ribs as shown in Fig. 4(b).

## **4. Conclusions**

In this paper, comparative studies on variation of the welding area and shift of the reinforcement were carried out by applying the optimization technique to core shroud for KSNP and KNGR, respectively. For the purpose of this study, 1) Optimization procedures were established using parameters in ANSYS, 2) 2-D axisymmetric models were developed.

From the results by application of optimization technique, it is expected ;

- Weld deformation occurred during core shroud manufacturing can be minimized by modifying the brace shape for the both KSNP and KNGR.
- Structural integrity of core shroud can be improved by relocating the rib and brace for KNGR. In the case of KSNP, however, these relocations may not affect its structural integrity.

It is a fact that the 2-D model has a rather restrictive insufficiency such as analytical uncertainties, expression in longitudinal or detail and thermal load case as already pointed out. Regardless of the insufficiency, it is still believed that the design optimization technique applied has proved to be very effective for a broad range of design modification on complicated structure as an initial approach method. The experience achieved here can be applied to the other structures by appropriate changes in the optimization procedure or modeling.

## References

1. "Design Specification for Reactor Vessel Core Support and Internal Structures for YGN 5&6", KOPEC (1998)
2. "ANSYS User's Manual - Rev. 5.1", Volume I & II, Swanson Analysis Corporation (1994)
3. E. J. Haug and J. S. Arora, "Applied Optimal Design", John Wiley & Sons Inc. (1979)
4. E. Atrek, R. H. Gallagher, K. M. Ragsdell and O. C. Zienkiewicz, "New Directions in Optimum Structural Design", John Wiley & Sons, Inc. (1984)
5. "Stress Analysis of the Core Shroud under the Normal Operating Loads for UCN 5&6", KOPEC (1999)
6. "Stress Analysis of the Core Shroud under Pressure and Thermal Loading for KNGR", KOPEC (1998)
7. "Drawing for Core Shroud Assembly for YGN 6", Hanjung (1998)
8. "Sketch for Core Shroud for KNGR", ABB-CE (1998)

Table 1. Optimization Results for KSNP & KNGR Core Shrouds

Optimization Parameters	Definition		KSNP		KNGR	
			Initial	Optimized	Initial	Optimized
Design Variables (inch)	Rib Location	n2y	6.0	5.9	7.1	7.4
		n3y	16.0	17.6	17.3	21.9
		n9y	27.8	26.4	39.2	33.3
	Brace Location	n10y	31.8	31.1	43.0	42.3
		n31x	57.8	57.7	65.5	65.3
	Brace Width	hbra2a	2.5	0.5	1.5	0.8
		hbra2b	3.0	2.2	2.5	1.8
		hbra2c	4.7	3.1	5.0	3.9
		hbra3a	3.0	2.1	3.0	1.8
		hbra3b	4.0	2.1	3.0	1.9
	hbra3c	6.0	4.5	5.0	3.9	
Objective Function (inch)	Sum of Brace Width		23.2	14.4	20.0	14.1
State Variables (psi)	Stress Bound (Constraint)		±10000		±15000	
	Max. S.I. ( $S_{max}$ )		9837	9866	24425	15075

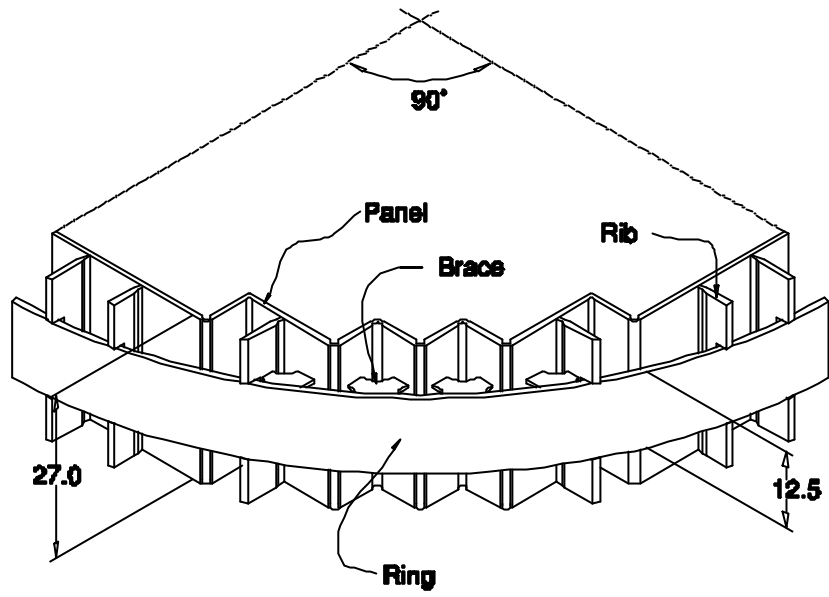
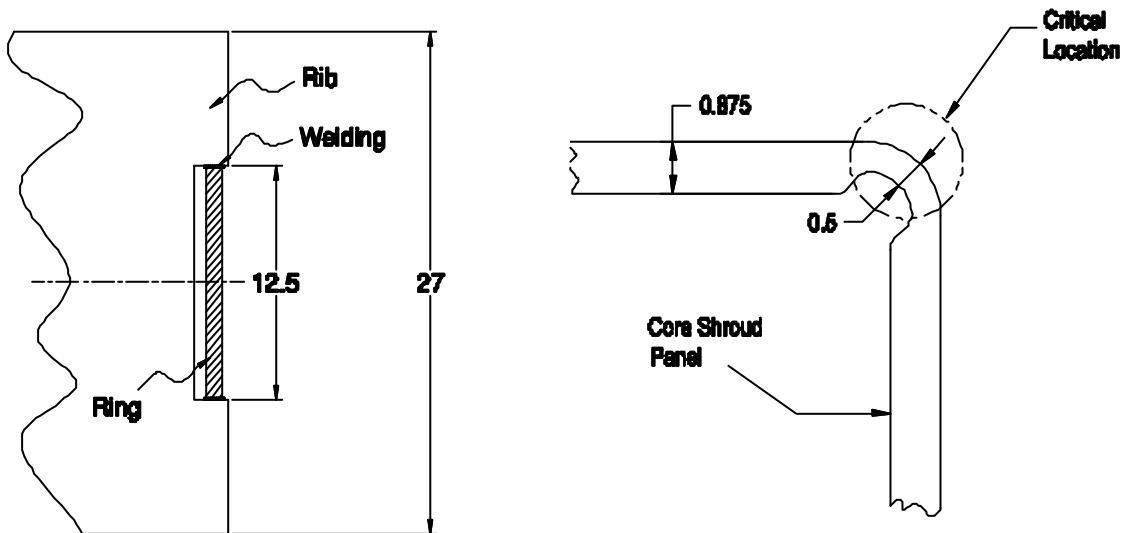


Figure 1. Core Shroud Configuration :  $\frac{1}{4}$  Part



(a) Longitudinal Aspect for Rib & Ring

(b) Corner Area of Core Shroud Panel

Figure 2. Geometrical Features of Core Shroud

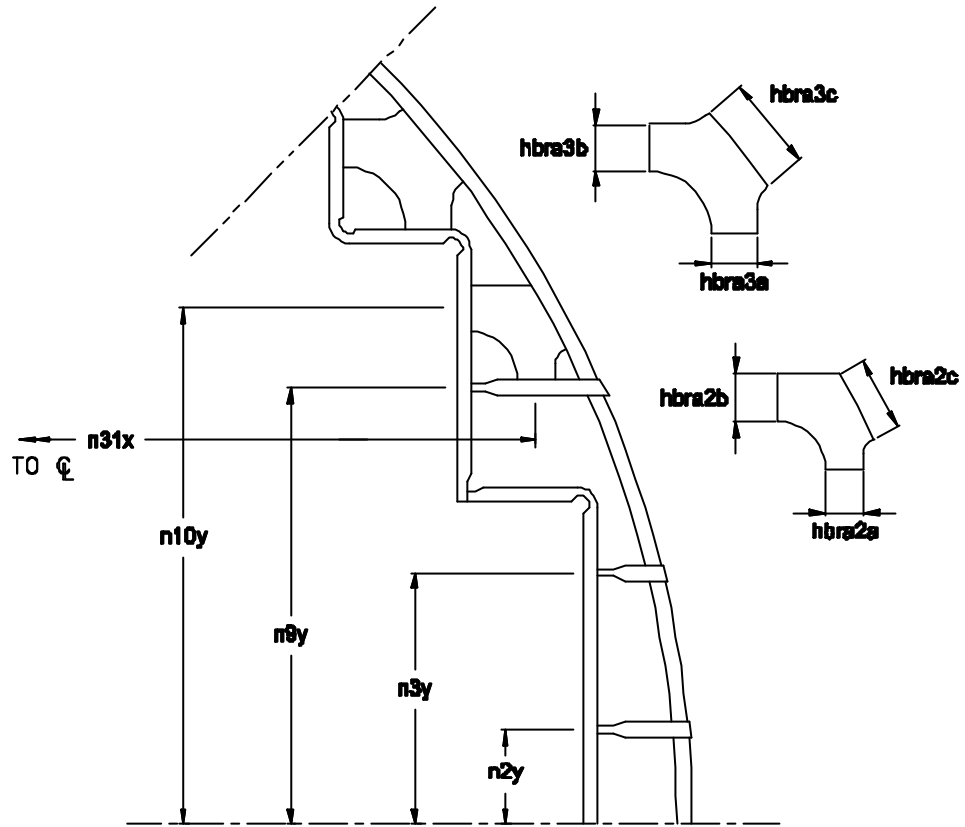
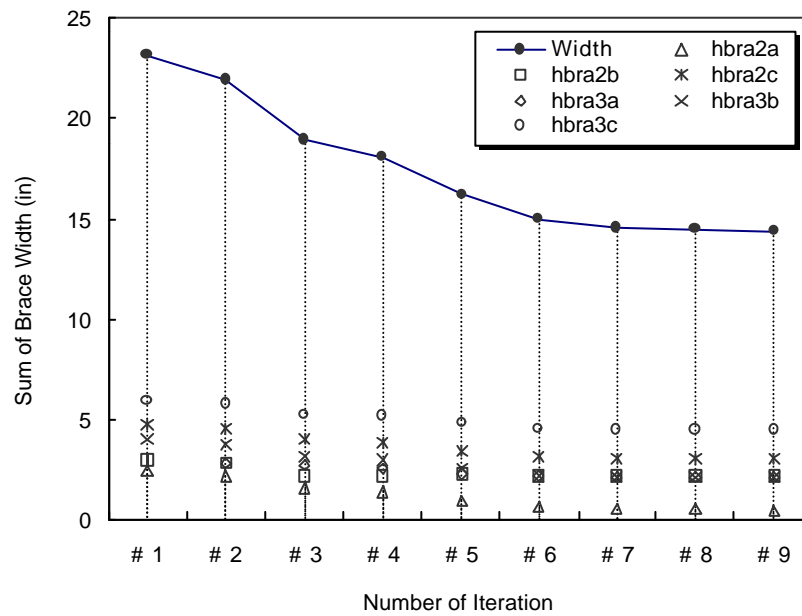
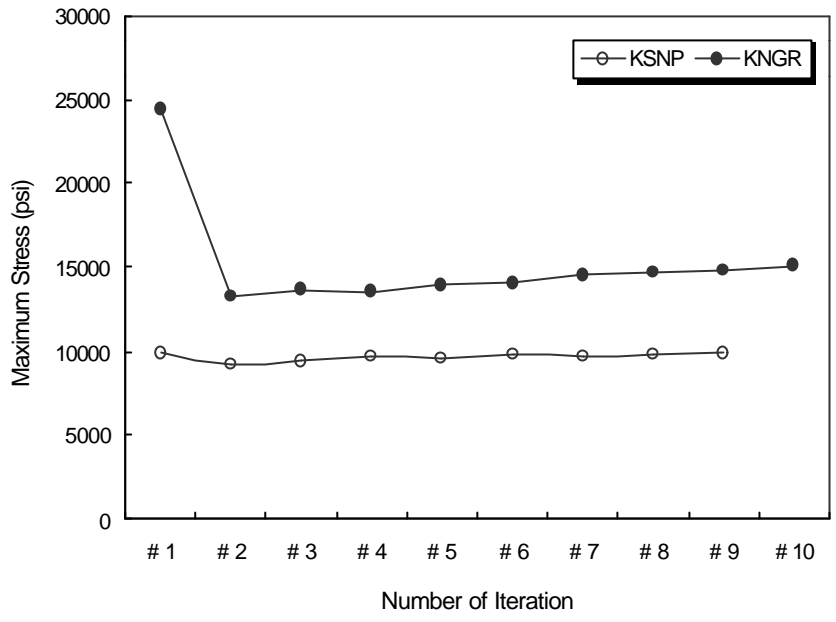


Figure 3. Optimization Parameters



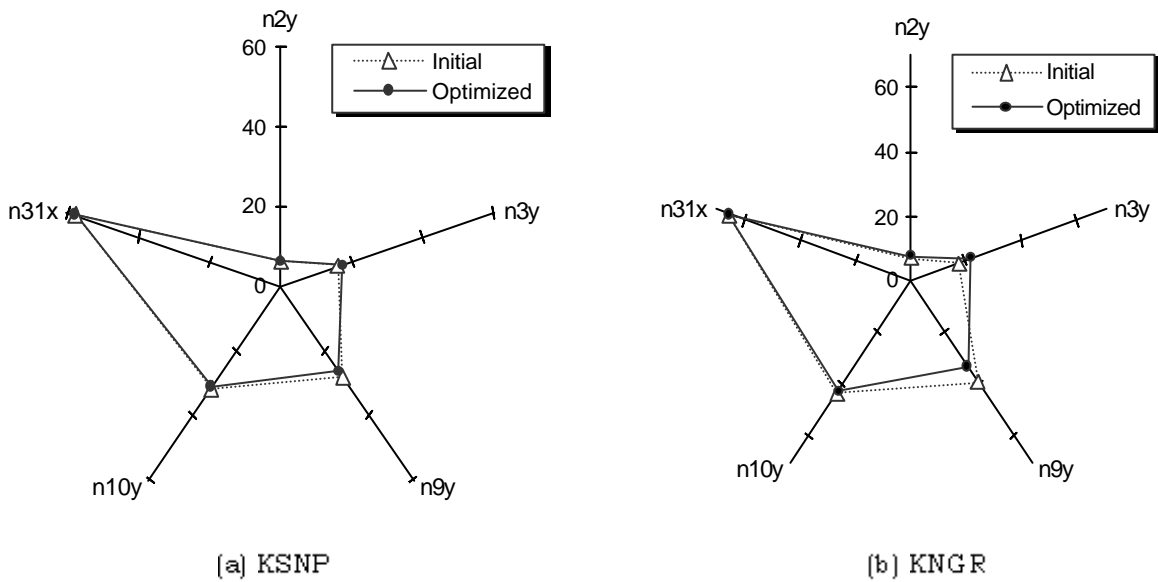
(a) Variation of Objective Function for KSNP





(b) Variation of  $S_{max}$

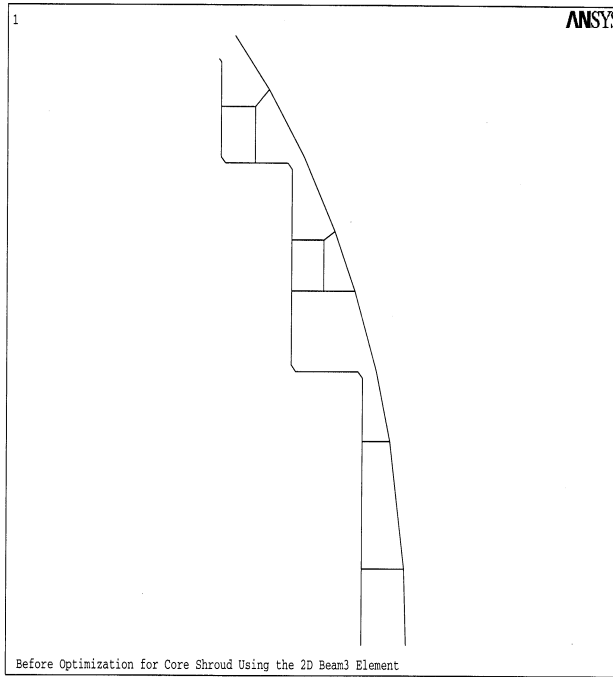
Figure 4. Optimization Convergence



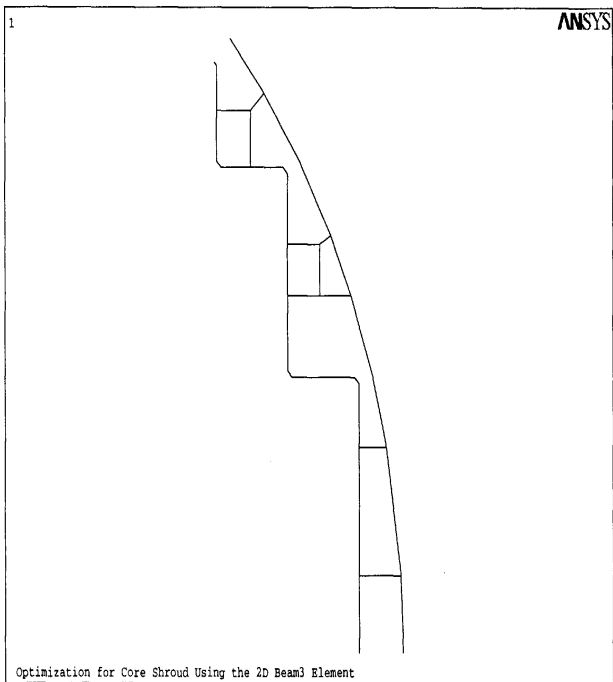
(a) KSNP

(b) KNGR

Figure 5. Optimization Result for Shift of Reinforcement

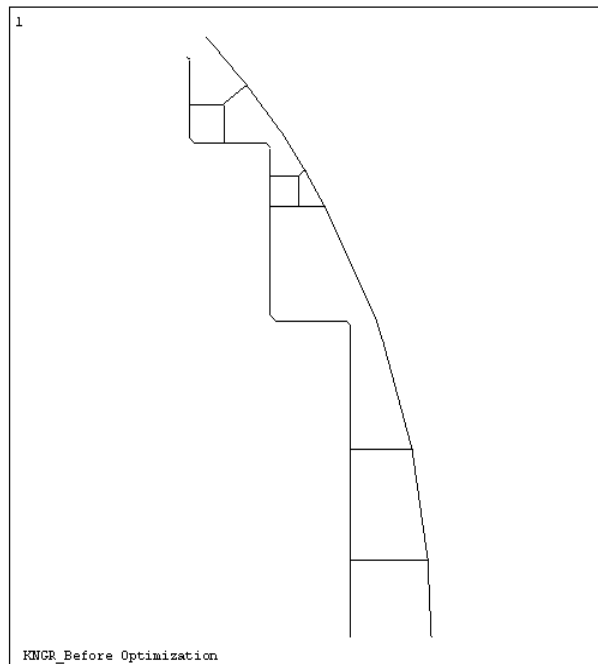


(a) Initial Design

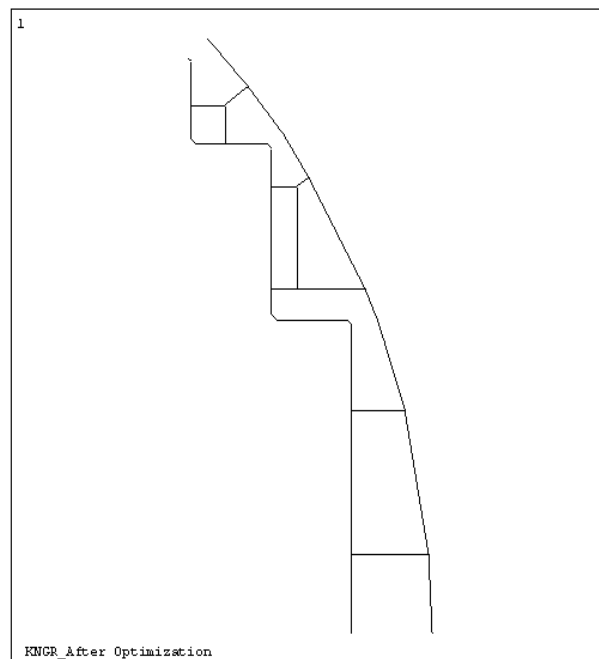


(b) Optimized Design

Figure 6. Geometrical Change by Optimization for KSNP



(a) Initial Design



(b) Optimized Design

Figure 7. Geometrical Change by Optimization for KNCR