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Concrete Encasement Design for Spiral Casing Under Refurbishment

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Abstract: ***Renovation, Modernization and Uprating (RMU) of old power stations are cost effective, environment friendly and require less time for implementation instead of creating new stations. The economy in cost and time essentially results from the fact that, apart from the availability of the existing infrastructure, only selective replacement of critical components is necessary. The turbine is a component which very often needs replacement owing to change in operating head and discharges. The choice is however constrained by the spiral casing which is embedded in concrete. Turbine designs must consider alternatives of designing a new turbine for the existing spiral casing (with its stay vanes) or replace the spiral casing. For the proposed RMU of an undergoing project[1], which has been implemented about 55 years back, it is proposed to install a new spiral casing over existing foundation by removing the second stage concrete and providing new second stage concrete after the installation. This has called for the design of second stage concrete encasement and this paper gives the methodology adopted in the design of second stage Concrete around the spiral casing.***

Keywords: Spiral Casing Encasement, RMU, Total Stresses, Principal Stresses, Tensile Stresses, Compressive Stresses and concrete

1. Introduction

The RMU of hydropower projects has several advantages over building new power plants. Site specific ecological studies and clearances are not needed. Issues related to population displacement can be avoided. Technically, hydrological and geological risks are avoided as the historical datasets yield well for analytics aiding a well justified decision making. Owing to the shorter gestation period, return on investment is improved also taking advantage of technological advancements.

A hydropower project built during 1960s had served its design life and came up for such a study. The DPR suggested retaining the civil structures owing to its superior quality. Mechanical components like hydraulic gates and penstocks were also retained.

Electromechanical equipment was proposed to be completely replaced considering the non-availability of spares and required performance guarantee, which would be difficult if a new vendor has to use old equipment.

The existing spiral casing was encased with concrete up to its centerline. The concerting done for the existing spiral casing was similar to the present practice where it is done in stages with final encasement placed as second stage concrete with first stage being brought to the level where the spiral casing pedestals rest.

The equipment vendor designed the spiral casing for half encasement and provided the forces to which the concrete encasement has to be designed.

The thickness of second stage concrete is about 1000mm. After placing the new spiral casing, the second stage concrete will be done up to the center line of spiral casing. Thus, the spiral casing is half embedded in concrete similar to that followed in existing spiral casing. Hence, it becomes necessary to do the concrete embedment design for supporting new spiral casing.

2. Input Parameters

As per the spiral casing supplier, the number of supports proposed for supporting spiral casing is 7. These are only temporary supports for erection and once surrounding concrete is done, the spiral casing will have continuous uniformly supporting system.

The plan and section of the proposed second stage concrete embedment details are shown in Fig-1.

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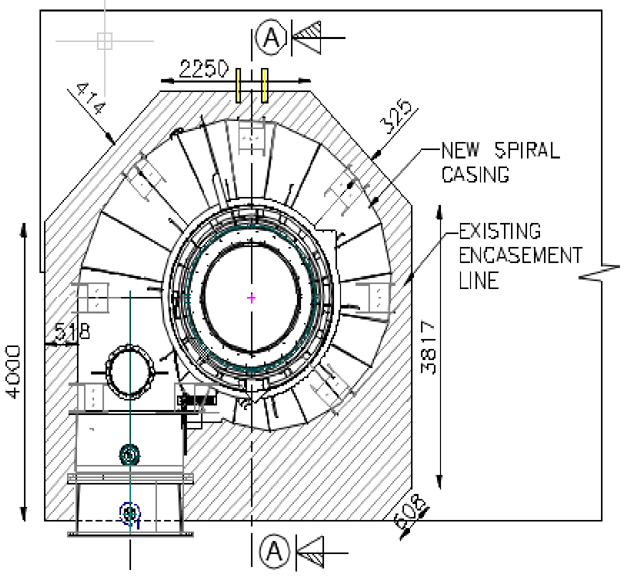
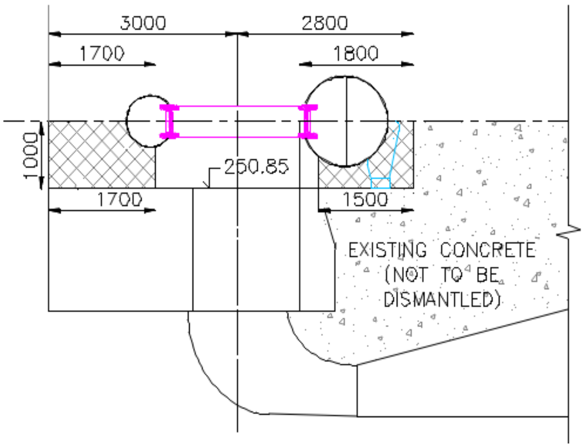
[1] The exact details of the project cannot be revealed due to confidentiality agreement with client.



(a) Plan



(b) Section A-A

Figure 1: Proposed second stage concrete embedment details of spiral casing.

3. Analysis Methodology

Finite Element Method of Analysis is adopted, using STAAD-Pro Software, for assessing the stresses developed in concrete surrounding the spiral casing. Half embedment in concrete is proposed for spiral casing to match in line with the old arrangement. Analysis is done using a simulated mathematical model of linear elastic properties.

The concrete embedment is modeled as a 3D solid element for spiral casing. The solid element is discretized with 8-noded hexahedral element. The spiral casing is modelled as plate element. The support condition considered for the concrete embedment is fixed at continuous edges and free at discontinuous edge. The 3D model of spiral casing and the concrete embedment is shown in Fig-2. The discretization of model is shown in Fig-3.

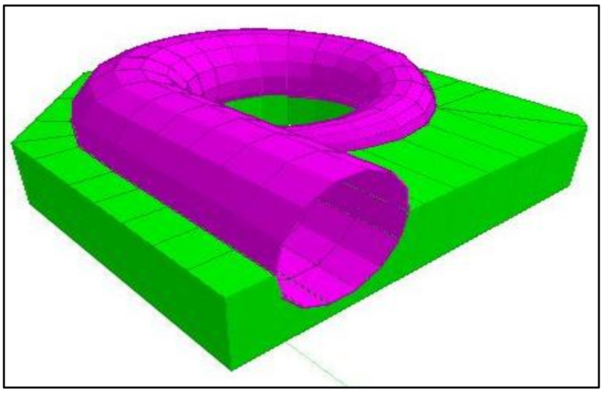


Figure 2: 3D Model of Spiral Casing and Concrete Embedment

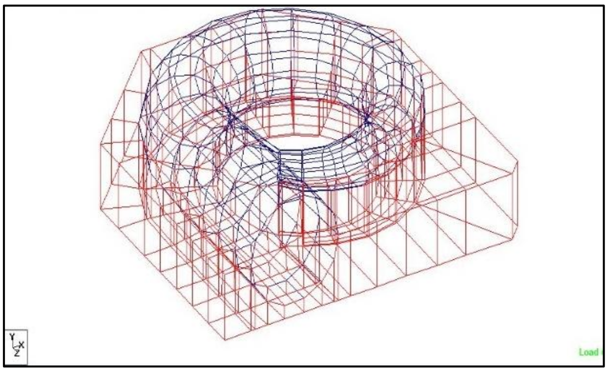


Figure 3: Model Discretization

The various loads and load combinations considered in the analysis are given in Table-1.

A concrete density of 25 KN/m³ is considered for self-weight calculation. Density of Steel is considered as 78.5 kN /m³ for calculating self-weight of spiral casing. As the surge pressure is more than normal operating pressure and as per IS: 11639 (Part 2) the surge pressure is to be considered under normal operating conditions, the analysis is carried out for the surge pressure with and without live load combination.

Table 1: Load and Load Combinations

S. no	Load Case	Load
1	Normal Operating Condition	734.2 kN /m²
2	Surge Condition	1131.1 kN /m²
3	Live Load around spiral casing over concrete	5 kN /m²
4	<u>Load combination</u> a) Self Weight + Normal operating pressure +Live load b) Self-Weight + Surge Pressure + Live Load	Self-Weight +734.2 normal pressure + 5 kN / Sqm Live Load Self-Weight + 1132 Surge Pressure + 5 kN / Sqm Live Load

4. Analysis Results

Finite Element Method of Analysis gives results in the form of stress contours. From these stress contours one can identify which part of the structure is stressed more under different load combinations. The element is designed for the maximum stresses developed under critical load combinations. The stress contours for various load cases are shown in Fig-4 & Fig-5.

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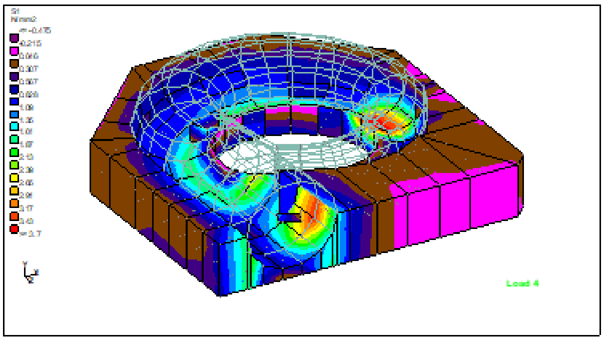

Figure 4: Stress Contour under Surge Pressure Condition

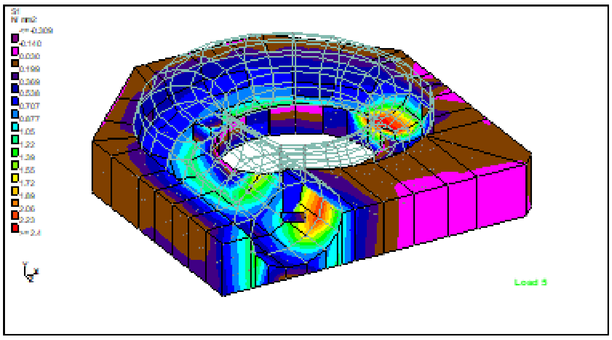

Figure 5: Stress Contour under Normal Pressure Condition

In the above stress contours, the positive values indicate tensile stresses, and negative values indicate compressive stresses. The axis–x and z are in the plane of paper and axis-y is perpendicular to the plane of paper.

5. Results Interpretation

FEM Software gives normal stresses, shear stresses and principal stresses acting on each element. The resulting stresses are total stresses in the element. From these total stresses, the stresses developed in concrete and reinforcement steel are calculated using the relation.

$$\sigma_i = \sigma_{ci} + \sigma_{si} \quad (1)$$

Where, σ = Total Normal Stress, σ_c = Normal Stress in concrete, σ_s = Stress in Reinforcement Steel and i = x, y and z directions.

The stress matrix for total stress is given in the following equation.

$$\begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} \quad (2)$$

Where, σ_x, σ_y, σ_z are total stresses and ζ_{xy}, ζ_{xz}, ζ_{yz} are shear stresses.

The reinforcement required in each direction is calculated using the relation

$$\rho_x = \left(\sigma_x + \{\tau_{xy} \pm \tau_{xz}\}\right)/f_y \quad (3)$$

$$\rho_y = \left(\sigma_y + \{\tau_{xy} \pm \tau_{yz}\}\right)/f_y \quad (4)$$

$$\rho_z = \left(\sigma_z + \{\tau_{xz} \pm \tau_{yz}\}\right)/f_y \quad (5)$$

Where, ρ_x, ρ_y, ρ_z = Percentage reinforcement in x, y and z directions respectively and f_y is the Yield Strength of Reinforcement Steel.

In the design of concrete members, as concrete is weak in tension, any tensile stresses developed in concrete will not be considered for sharing in concrete even though codes and standards permit to consider tensile stress depending on the grade of concrete. The tensile stresses developed in the member are taken entirely by reinforcement steel.

The minimum strength requirement for the concrete is checked with respect to the absolute maximum principal stresses developed in concrete. The concrete strength used in the members shall meet this requirement. Whenever the Compressive stresses are exceeding the permissible compressive stress in concrete, then reinforcement is provided to resist the balance stresses.

Normal stress in concrete σ_{ci} is calculated using equation (1). The concrete stress tensor is given in the following equation.

$$\begin{bmatrix} \sigma_{cx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{cy} & \tau_{yz} \\ \tau_{xz} & \tau_{zy} & \sigma_{cz} \end{bmatrix} \quad (6)$$

Where, σ_{cx}, σ_{cy}, σ_{cz} are normal stresses and ζ_{xy}, ζ_{xz}, ζ_{yz} are shear stresses in concrete.

The Eigen values of the Equation (2) and (6) respectively gives the Principal Stresses σ_1, σ_2, σ_3 of the total stresses and Principal Stresses σ_{c1}, σc_2, σ_{c3} of the concrete stresses acting on the element.

Once the normal stresses and principal stresses are known Mohr's circle is plotted for both total and concrete stresses and from this diagram reinforcement steel requirement in x, y and z direction is verified.

6. Concrete Embedment Design

The concrete embedment is designed for the load combination which gives the maximum stress in the elements. The design is carried out using the Working Stress Method.

M25, A20 Grade of Concrete and High Yield Strength Deformed bars having Yield Strength of 500 N/mm^2 are considered for the design. The permissible stresses in concrete and reinforcement steel are considered as 8.5 N/mm^2 and 275 N/mm^2 respectively as per Table 22 of IS 456.

From the results, the stress matrix for the maximum total stresses, in N/mm^2, developed in the Element Number - 1397 for the surge condition is given below.

$$\begin{bmatrix} 3.545 & -0.765 & -0.360 \\ -0.765 & -1.410 & 0.028 \\ -0.360 & 0.028 & -0.048 \end{bmatrix} \quad (7)$$

In the above stress matrix, positive value indicates tensile stresses, and negative value indicates compressive stresses.

The reinforcement required in each of the x, y and z directions, for the stress matrix in Equation-7, is calculated using Equations (3) to (5).

Concrete stresses in each of the x, y and z directions are calculated using Equation (1). The calculated values of the reinforcement and concrete stresses in each of x, y and z directions are given in Table-2.

Table 2: Concrete Stresses & Reinforcement in x, y and z directions

Stress in Concrete (N/mm^2)	Reinforcement
σ_{cx} = - 1.125	Astx = 1.70 % 25 dia bars at 200 c/c
σ_{cy} = - 0.793	Asty = 0.12 % 12 dia bars at 200 c/c
σ_{cz} = - 0.388	Astz = 0.22 % 16 dia bars at 300 c/c

The stress matrix for the concrete stresses, in N/mm^2, developed in Element - 1397 is given below.

$$\begin{bmatrix} -1.125 & -0.765 & -0.360 \\ -0.765 & -0.793 & 0.028 \\ -0.360 & 0.028 & -0.8 \end{bmatrix} \quad (8)$$

The Eigen Values of the Stress Matrix of Equation (7) and (8) gives, respectively, the Principal Stresses for the total and Concrete Stresses in Element – 1397. FEM Software also gives the results of the principal stresses for the total stress acting on the elements. The Principal Stresses in Concrete is to be calculated from first principles.

The Principal Stresses developed in the Element - 1397 for the total stresses and the Concrete Principal Stresses are given in Table-3.

Table 3: Principal Stresses

Element Principal Stresses (N/mm^2)	Element Principal Stresses in Concrete (N/mm^2)
σ_1 = 3.695	σ_{c1} = 0.000
σ_2 = -0.082	σ_{c2} = - 0.513
σ_3 = -1.526	σ_{c3} = -1.792

The Mohr Circle for total and principal stresses for the Element - 1397 is shown in Fig-5.

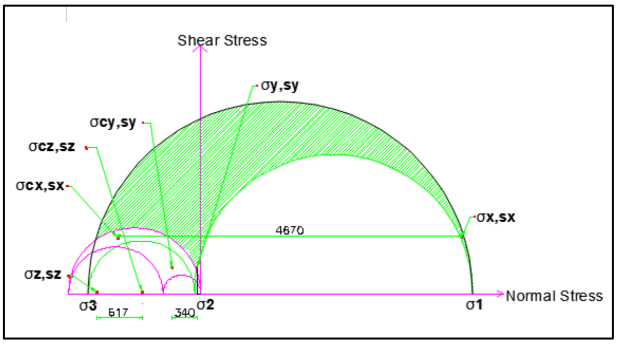

Figure 6: Mohr Circle

7. Conclusion

From the above analysis, the following conclusions are drawn.

The maximum total stress developed in Element - 1397 under surge condition is 3.545 N/mm^2 (Tensile) and the maximum Principal Stress developed is 3.695 N/mm^2 (Tensile). The tensile stress developed in the element is more than the permissible stress of 3.2 N/mm^2 for M25 Grade Concrete. Hence the tensile stresses developed in the element is resisted only by reinforcement steel.

From Table-3, it is observed that the minimum compressive strength of concrete required is 1.792 N/mm^2. The minimum grade of concrete used is M25 for which the permissible stress is 8.5 N/mm^2 which is greater than 1.792 N/mm^2. Hence the concrete grade used for second stage concrete embedment is satisfying the minimum strength criteria.

Reinforcement for second stage concrete is provided by drilling holes in the existing mass concrete, at required location, and fixed with grout.

Considering the quality and soundness of concrete used in the existing foundation it was recommended to remove only the second stage embedded concrete of spiral casing and redo the second stage concrete after installation of new spiral casing.

In case we go for the new foundation the total concrete requirement for the two foundations is around 200m^3. In the proposed method involving only the new second stage concrete, the quantity of second stage concrete for spiral casing is around 30m^3 for two units. Hence there is a saving of about 170m^3 of concrete in the foundation of two units. The reduction in quantity of 170m^3 concrete not only reduces the cost and time but also has indirect benefit to the environment as it reduces the production of cement by about 70MT thereby reducing the addition of carbon footprint in the environment. The reduction in concrete quantity also reduces the utilization of natural resources like aggregates and sand which are the main ingredients in concrete production.

Hence, in view of various advantages like reduction in cost, time and considering environmentally friendly aspects it is always recommended to use the existing foundation for supporting new equipment with minor modifications if quality and soundness of existing foundations meets the specification and code requirements instead of providing new foundations.

It is, however, worth noting that the old second stage concrete was removed using non-percussive methods which avoid undue stress on the old structure. Stitch core drilling followed by diamond wire cutting was adopted to remove old concrete which also has the added advantage of accurate removal of concrete. It has to be ensured that the reinforcement of the first stage or mass concrete is not disturbed.

Large spiral casing and particularly if it is completely encased in concrete may still necessitate the usage of old spiral casing. However, for spiral casing half encased in concrete, replacement of spiral casing is an alternative worth considering.

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