Stresses and Deformations in Concrete Encasing Spiral Case of a Hydro-turbine by Finite Element Method

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Abstract: **The spiral case of a hydro-turbine is embedded in concrete to transmit the loads of the generating units and ancillary equipments over it to the foundation. The surrounding concrete also acts as a shield to the steel spiral case and restricts its deformation. The stresses and deformations at different locations inside concrete around spiral casing of a hydro-turbine, subjected to static loads of the generators and other structures above it, are worked out using Finite Element Method (FEM), and presented in this paper. A 3-D model is considered as per the dimensions of the physical model tested by Nigam [1]. Total static load acting on the spiral case is applied uniformly on the concrete surface spreading over an annular area encircling the turbine pit to determine the normal stresses and deformations in the concrete. The results obtained by the FEM model are compared with those obtained by Nigam through photo-elastic method, which is an experimental one. Nigam's study revealed only the normal stresses in the concrete. But in the present study in addition to the above, deformations along different axes and shear stresses in separate planes are also computed. The ANSYS CAE software is used in conjunction with 3D CAD solid geometry to simulate the behavior of the structure under various loading conditions, and to generate the results. A comparative study results are presented in this paper.**

Key words: Hydro-turbine, Spiral case, FEM, PEM, Stresses in Concrete

I. INTRODUCTION

The steel spiral casing of a hydro-turbine is embedded in Reinforced Cement Concrete (RCC) to resist various static and dynamic loads transferred from the generating equipments and other related structures. The internal water pressure exerted on the steel spiral casing is also transferred to the embedded concrete. The intricate geometrical shape, complicated structural arrangements and varieties in loading pattern on the structure make the structural design of the RCC complex. The stresses developed in the concrete around spiral case and deformations are three dimensional. The knowledge regarding the actual structural behavior of this concrete structure is inadequate and prevalent design practices are only approximate. It is usual practice to design the concrete around the casing by beam-column arrangement, arch arrangement or ring arrangement. In order to work out a more realistic, economic and safe design an attempt is made in this study to investigate stresses and deformation in concrete around spiral casing due to various loading condition using Finite Element Method.

Very few works evolving exact solution of 3-Dimensinal mathematical analysis for such complex structures involving static and dynamic loads, geometrical variations and discontinuities are reported. P.S. Nigam (1976) [1] has done three dimensional analysis of concrete around spiral case by photo-elastic method. He has determined the stresses at various points due to static generator load only. Photo elastic-method is an experimental method to determine the stress distribution in a material. This technique is mostly used in cases where analytical methods become quite cumbersome and not feasible. Unlike the analytical methods of stress determination, photo elasticity gives a fairly accurate picture of stress distribution, even around abrupt discontinuities in a material. The method is an important tool for determining critical stress points in a material, and is used for determining stress concentration in irregular geometries. E.C.Kalkani, (1995) [2] worked on expected displacement and stresses in encasing concrete of a Francis Turbine scroll case by using finite element stress analysis. He has examined the minimum principal stresses in various cases those are found to be compressive and has higher stress concentrations close to be stay ring supports. Jahangir Bakhteri (2003) [3] has studied the effect of generator loads of a hydro-electric power house on concrete. In his paper linear elastic analysis is carried out using FEM and boundary element method (BEM). He has compared his results related to stress pattern with the stress pattern obtained by the photo-elastic method carried out by Nigam and others. It is revealed that the stress patterns of all the cases of his study are similar but the values differ whereas the stress patterns of various cases in photo elastic methods are different. Xinyong XU et al. (2009)[4] studied the contact state of spiral case and the peripheral reinforced concrete considering constant internal water pressure inside the spiral case, which causes an initial crack opening. They analysed on development of stresses and characteristics of the reinforced concrete around it. Hegao Wu et al. (2012)[5] worked on structural analysis of the embedded spiral case in the "three gorge hydropower station". Their research performs a three dimensional non-linear finite element static analysis of the concrete structure based on a damaged plasticity model to study the reliability of spiral case and the safety of the turbine units under different loading coordinates. Ze Li and Lixiang Zhang (2012)[6] studied three-dimensional damage analysis of concrete surrounding the spiral case under the repeated maximal water hammer pressure, establishing finite element model using ABAQUS software for the Nuozhadu Hydropower Station. Xin-yong XU et al. (2013)[7] studied the distribution and evolution of structural damage of concrete structure surrounding the spiral case through a physical model in laboratory. The same is also studied by simulating a three dimensional finite element model.

Analysis and computation of the stresses and deformations at different locations inside concrete encasing a spiral casing of Hydro-Turbine, subjected to annular uniformly distributed loading considering all similar loads as in case of Nigam [1] is presented in this paper. Nigam has developed few small scale power house models to determine the stresses at various points due to static generator load using photo-elasticity by stress freezing method, considering all static loads to be acting uniformly over an annular area. Here, a 3-D model of the spiral casing is made using ANSYS CAE (Computer-Aided Engineering) software in conjunction with 3D CAD (Computer Aided Design) solid geometry to simulate the behavior of mechanical bodies under structural loading conditions. The stresses along all three axes determined by the FEM model and are compared with those obtained by photo-elastic method. The probable deformations are also computed. ANSYS automated FEA (Finite Element Analysis) technologies were used to generate the results.

II. THE MODEL

A 3-D model of the scroll casing is prepared through CAD to simulate the actual geometry and its structural behavior. The dimensions of the model are considered as per the physical model of Nigam. It is assumed that the material is isotropic and within its elastic limit. The structural model resembles a parallelepiped block, which is enclosed on all four sides except the penstock opening. The diameter of the scroll case is gradually reduced. Four-nodded tetrahedral elements are considered for meshing of the model. Meshing of the model along with the loading positions is shown in Fig. 1.

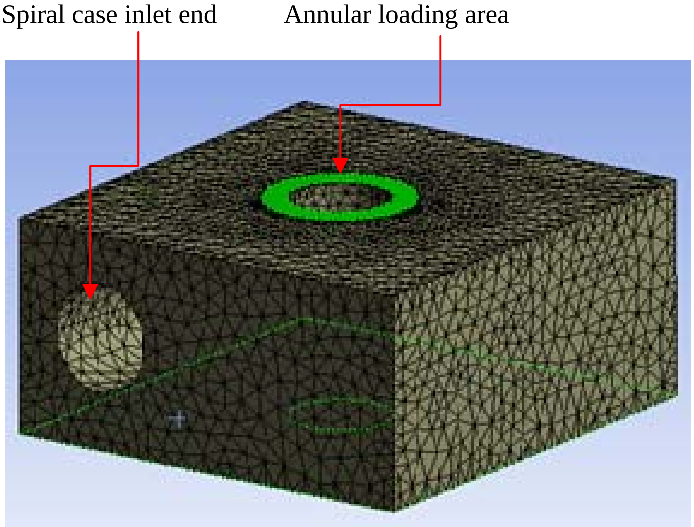


Fig. 1 Meshing of the model

III. ANALYSIS

The structure is analyzed for all vertical loads, which includes thrust at lower bracket level, stationary parts of generator (stator and rotor assembly), weight of stator pedestal, weight of concrete barrel, weight of barrel wall and loads transferred from generator floor. These loads are simplified into UDL in the form of a circular ring with a constant width in plan as indicated in Fig. 1. The stay vanes do not carry any loads and all the loads are transmitted to the foundation through concrete around spiral case. The normal stresses, deformations in three axes and shear stresses are computed. The physical properties of the concrete and details of loads considered in the study are presented in Table 1 and Table 2, respectively.

TABLE 1. Physical Properties of Concrete

Elastic Modulus (Pa)	Poisson's Ratio	Density (kg/m^3)	Compressive Strength Pa	Tensile Strength Pa	Thermal Expansion (/^{0}c)	Specific heat (J/Kg^{o}C)	Thermal Conductivity (W/m^o C)
3.0 x 10^{10}	0.18	2300.0	4.1x 10^7	5.0x10^6	1.4 x 10^{-5}	780.0	0.72

TABLE 2. Loads considered on Concrete for Analysis

Sl no	Details of load	Load (KN)
1.	Vertical load including hydraulic thrust at lower bracket level	3060
2.	Stationary part of generator	1050
3.	Wt. of stator pedestal	390
4.	Wt. of barrel	1450
5.	Wt. of sidewall of housing	840
6.	Reaction of floor	700
Note: Total load is applied uniformly over an annular area of 40.2 Sqm @ 17.5 KN/m^2		

As the bottom of the concrete block encasing the spiral casing is continuous from the foundation concrete, the analysis is done with considering the bottom of the model as fixed. Boundary conditions for all other sides are treated as free. The model is sliced into 21, 9, 12 sections in x, y and z axis, respectively, to visualize the stress patterns, as shown in Fig. 2 (a, b). Few typical sections showing the stress pattern of present study along with those of the similar sections obtained by Nigam[1] are presented in Fig. 3 to Fig.5, for comparison. Maximum deformations along all axes and shear stress in different planes are also shown in Fig. 6 (a, b, c) and Fig 7 (a, b, c), respectively, which is not computed by photo-elastic method.

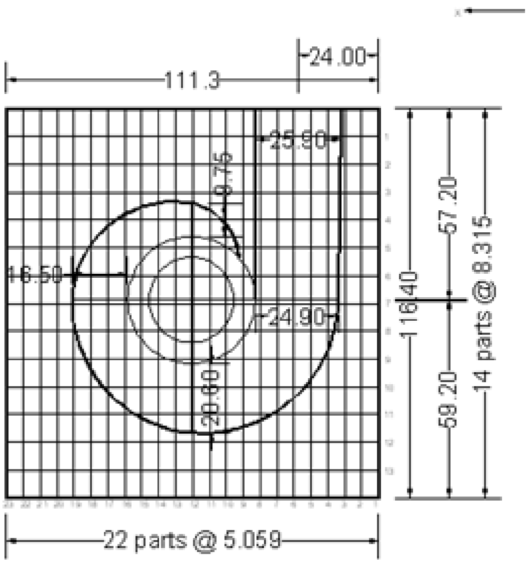


Fig 2(a) Slicing of model in X-Y Plane

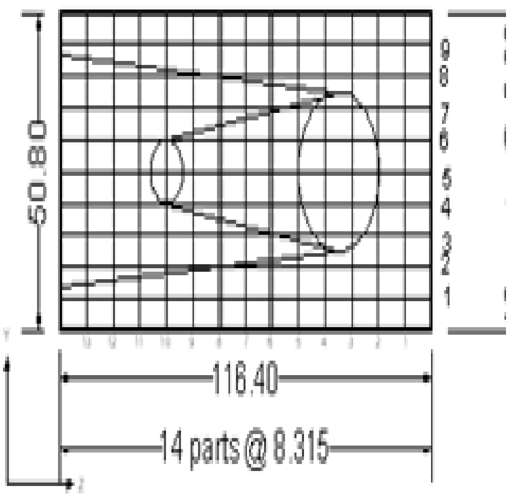
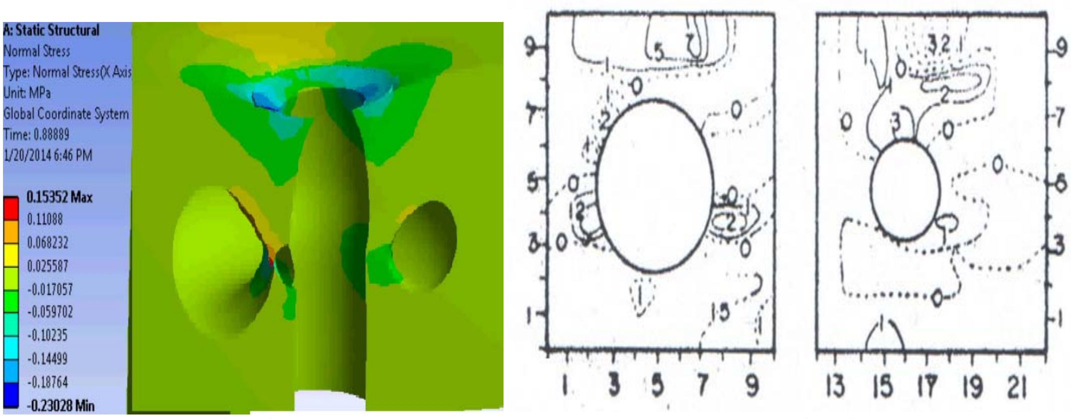


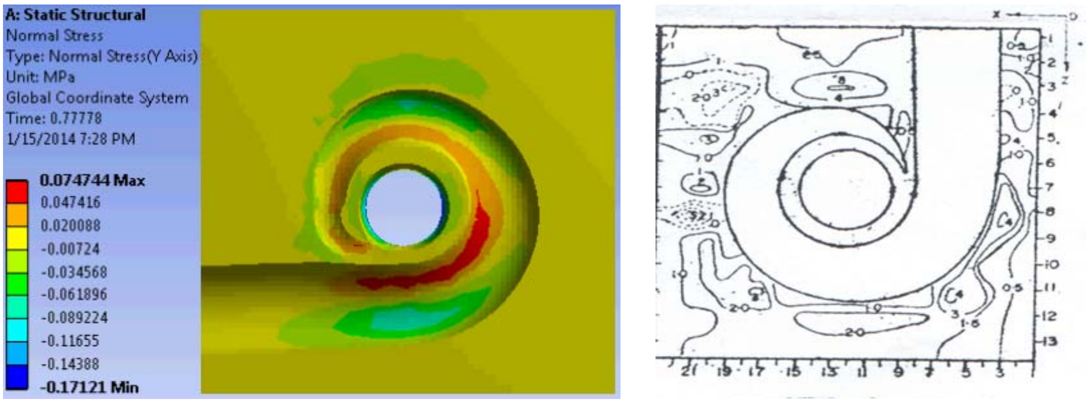
Fig 2(b) Slicing of model in Y-Z Plane

Note: The figures are extracted from the book "Hand book of Hydro-electric Engineering " by P.S. Nigam for comparison of results



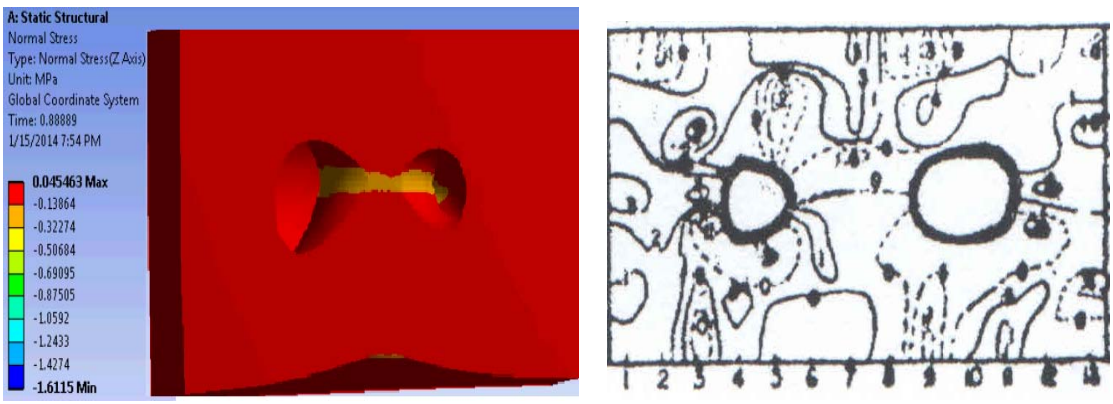
(FEM) (PEM)

Fig. 3 Normal Stresses along X-Axis, (Section 6)



(FEM) (PEM)

Fig. 4 Normal stresses along Y-Axis (Section 5)



(FEM) (PEM)

Fig. 5 Normal stresses along Z-Axis (Section 15)

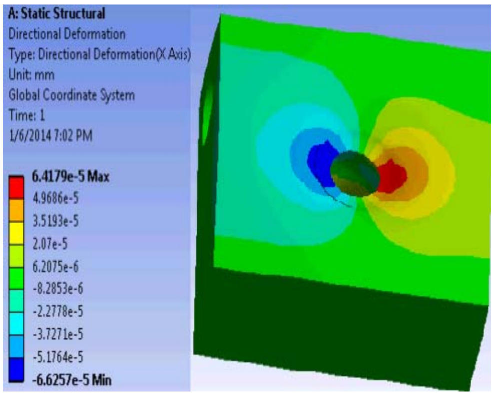


Fig. 6 (a) Total deformations along X-Axis

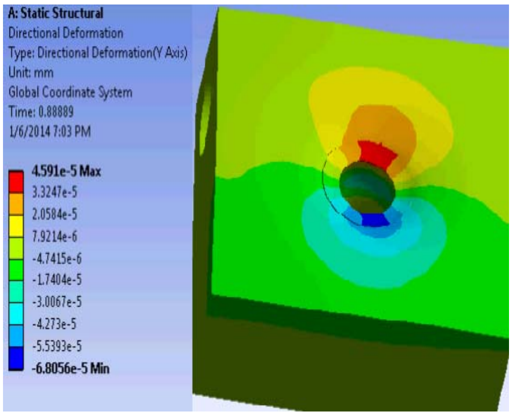


Fig. 6 (b)Total deformations along Y-Axis

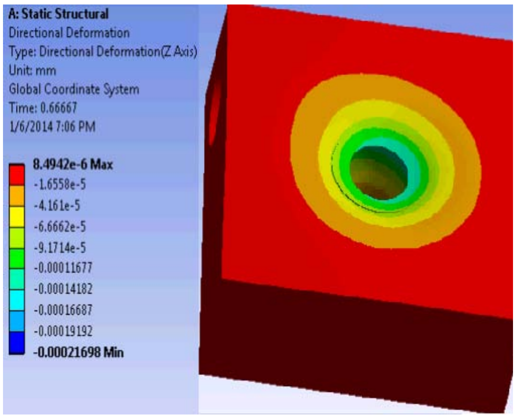


Fig. 6 (c) Total deformations along Z-Axis

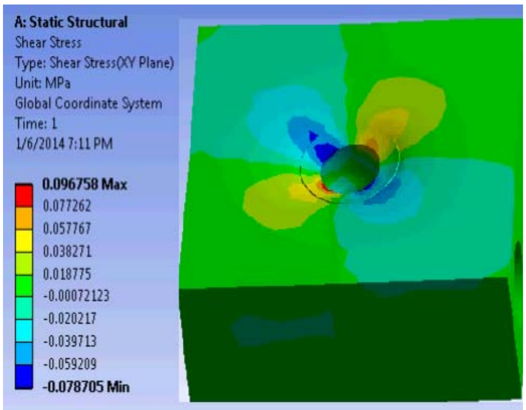


Fig.7 (a) Shear stress along XY-Plane

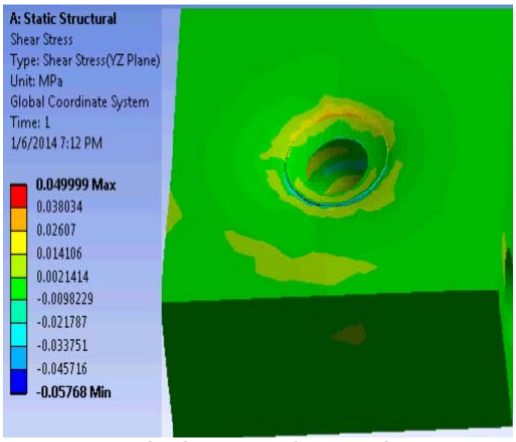


Fig. 7(b) Shear stress Along YZ-Plane

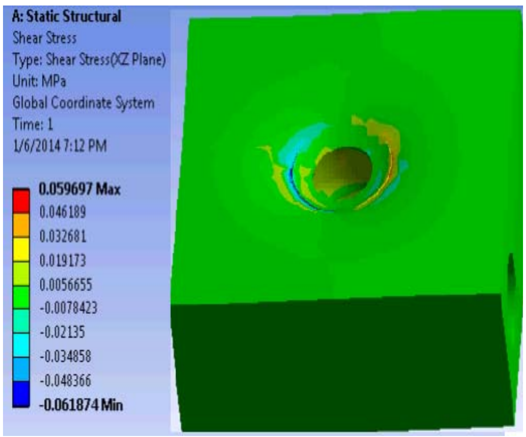


Fig. 7(c) Shear stress along XZ-Plane

TABLE 3. Comparison of Normal Stresses

Direction	Maximum Normal Stress (MPa)				Max Deformation (mm)
	Compression		Tension		
	FEM	PEM (Nigam)	FEM	PEM (Nigam)	FEM
X Axis	0.15352	0.90	0.23028	0.72	6.4179×10^{-5}
Y Axis	0.07474	0.072	0.17121	0.09	4.591×10^{-5}
Z Axis	0.04546	0.09	1.6115	1.62	8.4942×10^{-6}

IV. RESULTS AND DISCUSSION

Normal stresses along all three axes are computed through FEM and presented in Table 3. As the minimum values of compressive and tensile stress are zero only the maximum values are presented. In the Photo elastic method, the stress contours are represented in terms of Stress Concentration Factors (SCF). Actual stresses are calculated multiplying SCF with the average stresses. Stresses obtained from the stress-contours provided in various sections through PEM are also presented for comparison.

It is observed that the maximum normal stresses (tension and compression) obtained through FEM and PEM along Y-axis and Z-axis are comparable. But in case of X-axis above stresses vary widely. The reason for the differences is not clearly understood but it may be attributed to the dimensional effect of the physical model, as the sectional area of concrete is least in Z- direction.

The pattern of normal stresses in corresponding sections for both cases, i.e., FEM and PEM, along X, Y and Z axes are shown at Fig. 3 to Fig. 5. It is observed that the stress patterns for both the cases are similar but the values vary. The same was also observed in case of Jahangir Bakhteri [3]. In the present study it is noticed that maximum stresses along X-axis, develop towards the inner surface of upper portion of the spiral casing. Along Y-axis the maximum stress develop at central portion of bottom of the spiral case. But in case of Z-direction the maximum stresses develop almost over entire area. But all the stresses are of the order of 0.05MPa, which is negligible.

Total deformations along X, Y and Z axes are presented in Fig 6 (a, b, c), amounting to 6.41×10^{-5}, 4.59×10^{-5} and 8.49×10^{-5}, respectively, which are insignificant.

The maximum values of shear stresses along XY, YZ and XZ plane, shown in Fig 7 (a, b, c), are 0.096, 0.049 and 0.059MPa, respectively. Those are well within the safe limit of shear strength.

V. CONCLUSION

A comparative study between the results obtained from Photo-Elastic Method and Finite Element Method is presented. PEM being an experimental method, the accuracy of the results depends on the material property, dimensional precision, quality of the model and accuracy of experiment. Nigam has computed only normal stresses by PEM. But in the present study other parameters such as total deformations and shear stresses are also obtained in addition to normal stresses along all axes. It is seen that in both the cases the normal stresses along Y and Z directions almost matches. But in case of Z direction value of normal differs. This can be attributed to the dimensional constraint of the model as the cross section area of the physical model in that direction is least.

The results of the present study are presented in form of figures (Fig 3 to Fig 7). It is observed that maximum normal stresses and deformations in concrete occur towards the inner face of concrete, which matches the studies of Kalkani [2]. The shear stresses along all the planes are well within the safe limit. Hence while designing the RCC around spiral case adequate reinforcement is to be provided considering these stresses, instead of the beam and column theory [8, 9].

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