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Couple-Field Analysis of Steel Chimney

Linda Ann Mathew

Assistant Professor, Department of Civil Engineering, SBCEW, Elavumthitta, Kerala.

Abstract: ***Chimneys are required to carry vertically and discharge, gaseous products of combustion, chemical waste gases, and exhaust air from an industry to the atmosphere. Chimneys are tall structures and the major loads acting on these are self-weight of the structure, wind load, imposed load due to lining and other mountings, thermal load, earthquake load. In this paper a steel chimney will be designed considering dead load and wind load. The Bureau of Indian Standards (BIS) design codes procedures will be used for the design of the chimney. The chimney was considered as a cantilever beam with annular cross section. A simplified model of chimneys with various thicknesses like 6mm, 8mm, 10mm, and 12mm were modelled and analyzed using ANSYS and found that the chimney is more stable at the lower thickness of 6mm, so the chimney can be made cost effective at the lower thickness. In this paper the coupled-field analysis (thermal stress calculations) of the steel chimney with 6mm thickness was carried out and checks whether the stress distribution of the model exceeds the yield strength of the material or not.***

Keywords: steel chimney, annular cross section, couple field analysis, thermal stress.

1. Introduction

Chimney, which form the last component of a system using a flue gas such as boiler, play a vital role in maintaining efficiency, draft, etc, of a system and also in minimizing the atmospheric pollution. Steel chimneys are also known as steel stacks. The steel chimneys are made of steel plates and supported on foundation. The steel chimneys are used to escape and disperse the flue gases to such a height that the gases do not contaminate surrounding atmosphere. The cross sectional area of the steel chimney was kept large enough to allow the passage of burnt gases. When the gases in a steel chimney are heated, then the gases expand .The hot gases occupy larger volume than before. The weight of gases per cubic meter becomes less. For the purpose of the structural design of the steel chimney, the height and diameter of chimney at the top are known data.

A coupled-field analysis was a combination of analyses from different engineering disciplines (physics fields) that interact to solve a global engineering problem; hence, we often refer to a coupled-field analysis as a multi physics analysis. When the input of one field analysis depends on the results from another analysis, the analyses are coupled. To perform coupled-field analysis (thermal stress), we have two approaches, direct method and sequential method. In direct method we can use couple field element type to perform the analysis, in a single step, means we can combine all structural and thermal data's together, in just one analysis. In this sequential method, only two element types were used in mapping thermal results as structural temperature loads, it takes a little time to perform but we can have independent results of thermal analysis separately. Sequential method was used in this work.

2. Sequential Thermal-Stress Analysis

In this paper, the type of analysis used was a sequential thermal-stress analysis which involves two stages of analysis: (1) thermal analysis and (2) structural analysis. In this analysis the nodal temperatures from the thermal analysis were applied as loads in the subsequent stress analysis. Physics files can be used to perform the coupled-field analysis which was based on a single finite element mesh across the physics. The physics file was read to configure the database and then a solution was performed. After this, another physics field was read into the database and coupled-field loads were transferred where the second physics was solved. Coupling occurs by issuing commands to read the coupled loads from one physics environment to another across a node-node similar mesh interface.

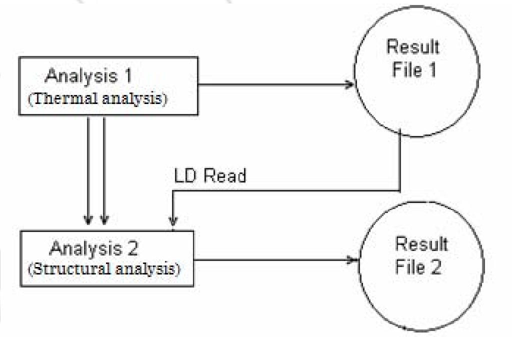

Figure 1: Data Flow for a Sequential Coupled-Field Analysis

The data flow for the present sequential analysis was done with the indirect method which was ideal for one-way sequential coupling such as a typical thermal-stress analysis. Each database contains the appropriate solid model, elements, loads etc. and the information was read from a result file into another database. The elements and the node numbers must be consistent between the database and the result file.

3. Analysis of Steel Chimney

In this study the steel chimney with 6mm thickness was taken for performing the coupled-field analysis to check whether the stresses were within the safe limits by also considering the effects of temperature. The analysis was carried out using ANSYS software. Temperature has a greater effect on the structural properties of the material so in this analysis the effects of temperature are also considered. After the analysis the thermal stresses and the deflection of the steel chimney are obtained from the finite element model of chimney. The coupled field analysis carried out at two stages - firstly the thermal analysis and secondly the structural analysis. For the analysis purpose chimney was modeled as vertical cantilever fixed at the base having annular cross section. The model taken was same as that for linear analysis. Plane77 element type was used for the first stage of analysis i.e. the thermal analysis and for the structural analysis the element type was automatically changed to plane183 by the system.

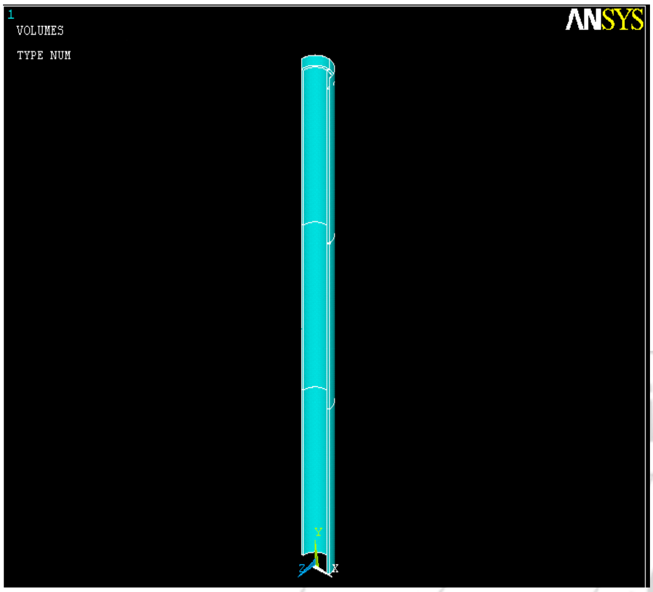

Figure 2: Axi-Symmetric Model of Steel Chimney for Coupled-Field Analysis

A. Stage.1: Thermal Analysis

In the sequential thermal stress analysis, the element type used for the thermal analysis was PLANE77. This element type has eight node thermal elements where the temperature has one degree of freedom. The material property which was thermal conductivity was assigned after the model was generated. PLANE77 was a higher order version of the 2-D, 4-node thermal element PLANE55. The element has one degree of freedom, temperature, at each node. The 8-node elements have compatible temperature shapes and are well suited to model curved boundaries. The 8-node thermal element was applicable to a 2-D, steady-state or transient thermal analysis. If the model containing this element was also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as PLANE183). The geometry, node locations, and the coordinate system for this element are shown in Fig.3.

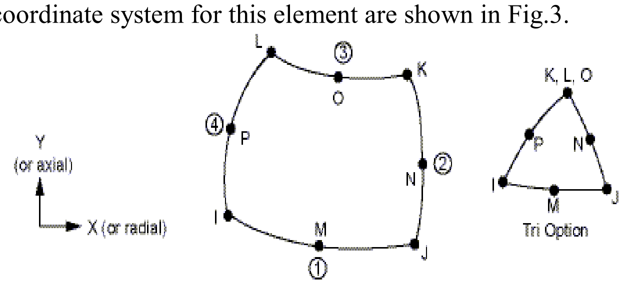

Figure 3: PLANE77 Element

(a) Material Properties

Material Model Number 1 refers to the steel chimney and Material Model Number 2 refers to the brick lining. The element requires density, linear isotropic (Young's modulus), thermal expansion (Secant Coefficient) and thermal conductivity (isotropic) material properties to properly define the models and was shown in Table.1. Parameters needed to define the material models can be found in Table 2.

Table 1: Material Properties of Chimney With Annular Cross-Section for Coupled-Field Analysis

Material properties	Shell	Brick lining
Young's Modulus (N/m^2)	2.1E+011	1.5E+010
Density (kg/m^3)	7850	700
Thermal Expansion (Secant Coefficient) ((^{0}C)-1)	1.3 E-005	2E-006
Thermal conductivity (isotropic) (W/mK)	45	0.23

Table 2: Material models of the chimney model for coupled-field analysis

Material model number	Element type	Material properties	
1	Plane 77	Linear isotropic	
		EX	2.1E+011
		PRXY	0.3
		Density = 7850	
		Thermal Expansion (Secant Coefficient)	
		ALPX	1.3E-005
		Thermal Conductivity (isotropic)	
		KXX	45
2	Plane 77	Linear isotropic	
		EX	1.5E+010
		PRXY	0
		Density = 7850	
		Thermal Expansion (Secant Coefficient)	
		ALPX	2E-006
		Thermal Conductivity (isotropic)	
		KXX	0.23

(b) Meshing and loading

The two-dimensional model was meshed using a triangular mesh as in the previous case. The meshing of the model was carried out using smart size mesh (mesh range 2 or 3). After the meshing process has completed then the temperature was applied.

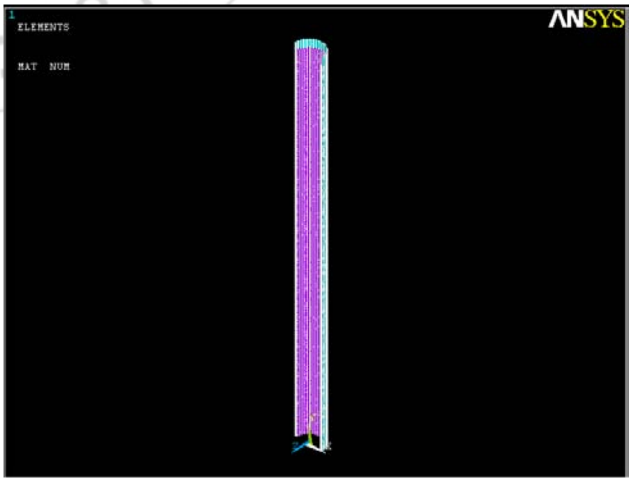

Figure 4: Meshed Model of Steel Chimney for Coupled-Field Analysis

B. Stage.2: Structural Analysis

Once the model was solved for the thermal analysis we return to the model creation preprocessor in ANSYS. Then the element type was switched from thermal to structural and the structural element type used was PLANE183. Once the element type was switched, the structural material properties, such as, the Young's modulus and thermal expansion coefficients were assigned to the model. The thermal expansion coefficients of the materials used change with change in temperatures.

(a) Boundary conditions and loading

As the element type used was compatible with that of the thermal model, the mesh involved in the structural analysis was also a triangular mesh which corresponds to that of the thermal model. For the structural boundary conditions, the temperatures from the thermal analysis were used as nodal loads, which were read into the structural model in ANSYS. Along with the thermal load the self weight and the wind loads were also introduced into the structure as in the previous case.

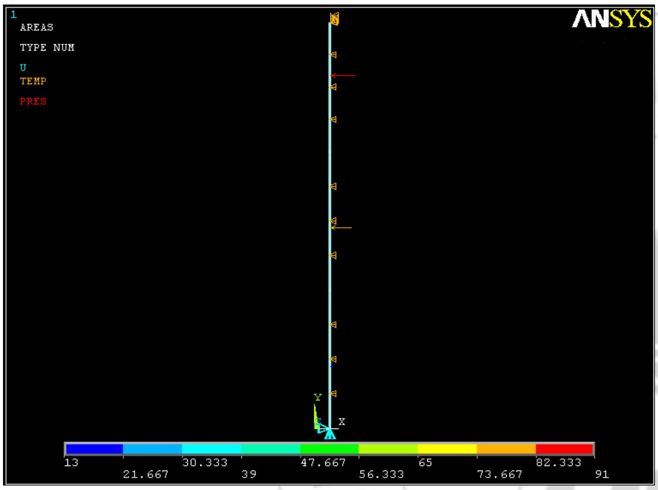

Figure 5: Loaded diagram of axi-symmetric model for coupled-field analysis

4. Result and Discussion

The coupled-field analysis of the proposed model i.e. steel chimney with 6mm thickness was performed. After the analysis the results obtained were checked and by comparing it with the result of linear analysis of 6mm thick chimney it was found that the stress distribution of the proposed model were within the safe limits. The maximum stress was obtained near the supports and minimum near the top portion of the chimney.

Table 3: Comparison of results of linear analysis and coupled-field analysis

	von Mises stress (MPa)
Linear Analysis	4.62
Coupled-Field Analysis	4.54

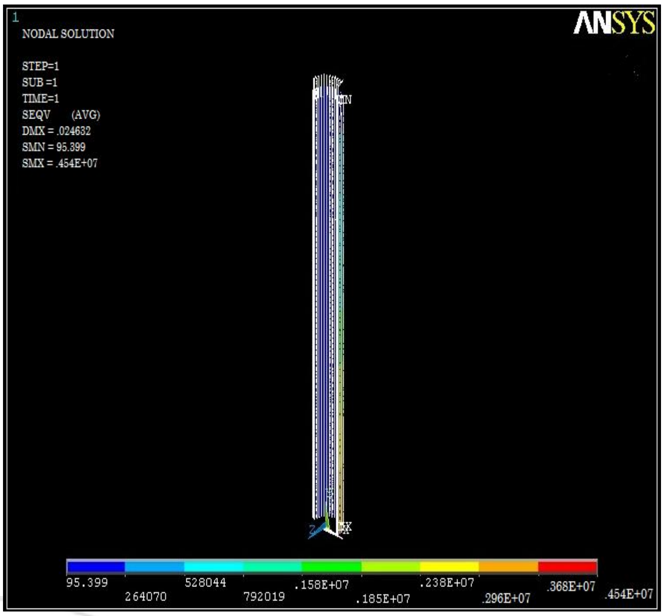

Figure 6: Thermal Stress Distribution and Deflection of Steel Chimney

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