Analysis and Upgradation of Pavement at Cochin International Airport for Higher Version Aircrafts

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ABSTRACT:- **The growth of air transportation is one of the most remarkable technological developments of last century. The phenomenal increase in air-travel has created severe congestion at the airports in the large cities, needing additional facilities. "Analysis and upgradation of pavement at cochin international airport for higher version aircrafts" is a project work that aims to modify the existing runway at Cochin International Airport to accommodate code F aircrafts considering all the factors. Topographic survey and Reconnaissance surveys are done in and around the proposed airport site. FAA guidelines and ICAO design criteria are strictly followed in the design of the runway. FAA designed software tool like FAARFIELD was used to design the structural airfield pavement and ABAQUS is used to perform the stress analysis of the runway.**

Keywords: GEOMETRIC DESIGN, FAARFIELD, ABAQUS.

CHAPTER 1

INTRODUCTION

1.1 Background

The growth of economy of any country depends upon the development of transportation. In country like India, having second largest system of railways in the world and fully developed highway transportation, there is growing demand for air transportation. Demands for larger capacity and more facilities at the airports are increasing at a faster rate. Runway is one of the essential part of an airport.According to the International Civil Aviation Organization (ICAO), a runway is a "defined rectangular area on a land aerodrome prepared for the landing and takeoff of aircraft". Runways may be a man-made surface (often asphalt, concrete, or a mixture of both) or a natural surface (grass, dirt, gravel, ice, or salt). Indian airport besides runway capacities are also lacking very much in accommodating new airline offices and their demands for handling passengers. Trivandrum international airport is the first airport in the state of kerala, India and it was the fifth international airport of India. Cochin International Airport (CIAL) has grown rapidly becoming the largest International Airport in Kerala and 4th largest in India in terms of international passenger traffic in just four years. The objective of our project is to analyze the forces coming on the runway of Cochin International Airport and to make the runway suitable for accommodating code F aircrafts and also to study the passenger flow and aircraft flow in the last 10 years and to propose a new parallel runway, if needed.

1.2 Need of study

- The passenger and aircraft flow details at CIAL for the last 10 years were collected and studied. Graph is plotted and extended for the next 10 years. The graph shows that the air traffic flow will increase rapidly for the next 10 years.
- The air traffic flow will increase rapidly for the next 10 years.

YEAR	PASSENGER MOVEMENT		
	INTERNATIONAL SECTOR	DOMESTIC SECTOR	TOTAL
2006-07	1429172	1131898	2561070
2007-08	1770612	1567530	3338142
2008-09	2010114	1352687	3362801
2009-10	2232346	1713757	3946103
2010-11	2359937	1985242	4345179
2011-12	2588032	2135361	4723393
2012-13	2934017	1965970	4899987
2013-14	**3271755**	**2114708**	**5386463**
2014-15	3745043	2682929	6427972
2015-16	4641127	3129658	7770785
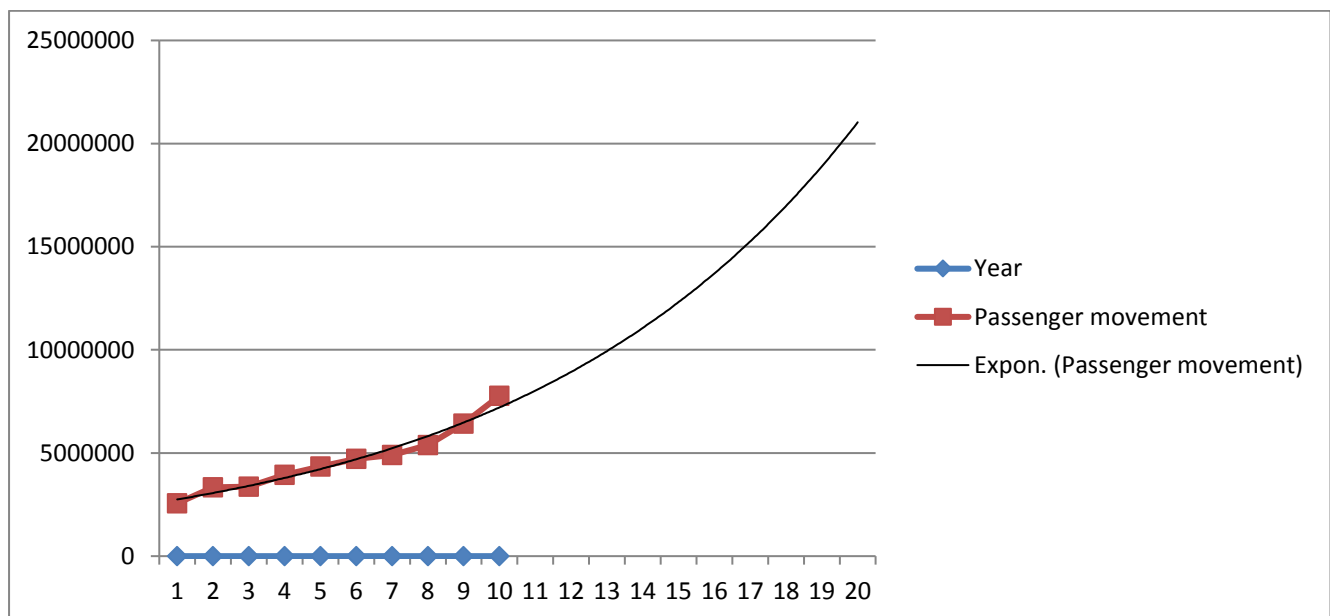
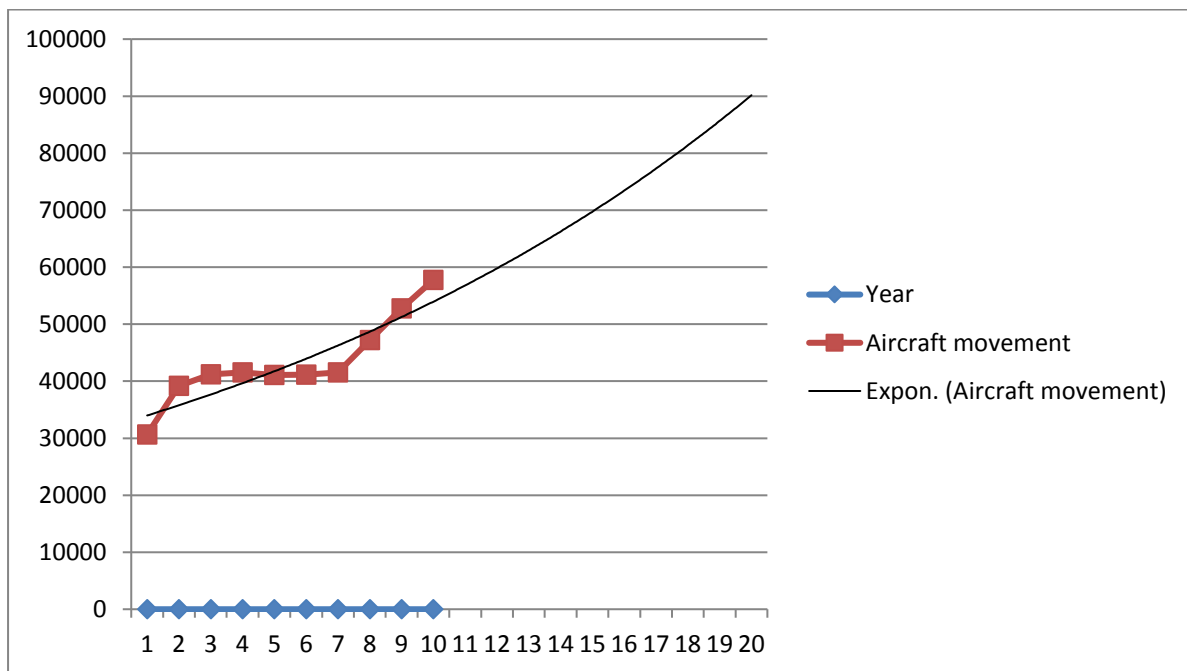| YEAR	AIRCRAFT MOVEMENT		
2006-07	14172	16501	30673
2007-08	16335	22833	39168
2008-09	19047	22125	41172
2009-10	18068	23476	41544
2010-11	18465	22615	41080
2011-12	18324	22817	41141
2012-13	20286	21252	41538
2013-14	23134	24082	47216
2014-15	25929	26855	52784
2015-16	29861	27901	57762

Chart 6:

At present, the runway at CIAL is a code E runway which has the ability to accommodate the aircrafts upto Boeing777. So to handle higher version aircraft like Airbus380, we have to upgrade the strength and dimensions of existing runway. This will helps to meet the increasing passenger flow.

- The proposal for a new runway will also meet the same demand.

1.3. Scope and Objectives

Objectives:

- To upgrade the pavement features at Cochin International Airport for code F aircrafts.

- To develop structural design of the pavement using FAARFIELD.

- To analyse stress at different nodes of pavement using finite element method (ABAQUS)

Scope of the project:

Cochin International Airport is the busiest and largest airport in Kerala. The passenger flow and aircraft movements at this airport was increased rapidly for the last few years. So the upgradation of the existing runway and the construction of new runway is become necessary. We aim to make a proposal for making the existing code E runway to code F for accommodating larger aircrafts and to construct a new runway.

CHAPTER 2

LITERATURE REVIEW

Sundeep Chowdary Daggubati (et al) concentrates on the design aspects of runway and its structural design which includes the region specific and real time collection of field data, computerized wind analysis and Orientation of the runway. Computerized system of design is discussed and solutions are arrived in detail. The runway is designed for the current trend new large aircrafts by considering their future increase in the number of annual departures. This is one of the comprehensive efforts to focus the preliminary report preparation of a typical airport's runway design. Runway geometry and orientation along with the structural design of the flexible airfield pavement are obtained successfully by using software tools which are strictly in accordance with the ICAO design criteria and FAA guidelines (Advisory Circular).

Sukumaran et.al. (finite element modeling of flexible pavement) discuses about the use of finite element analyses techniques to determine the failure mechanism in a pavement system under moving aircraft loads. The flexible pavement system is modeled on a medium strength subgrade. The stress-strain response of the medium soft clay is simulated using an elasto-plastic model.This paper presents the modeling of three-dimensional analysis of pavements. The issues of mesh construction,mesh refinement, element aspect ratios and material non-linearity's are discussed.

R Srinivasakumar, the author of Transportation Engineering-Airports discuss about the estimation of design runway length by ICAO (Part 1,Doc 9157,AN/901,2006). The length of primary and secondary runways will be determined based on the performance data of aircrafts for which the runway is intended to be used.If such data is not available,the actual length of runway in a proposed aerodrome may be determined by application of general corrections to the basic runway length.

"Investigation of Runway Pavement Design Software and Determination of Optimization Software" was done by Ahmad Mansourian et.al. In this paper, five typical pieces of software on the runwaypavement design are evaluated, so that first, structure of each piece of software mentioned in the runwaypavement design is addressed and then design of the sample airport is performed by each piece of software, andthe thickness of the pavement and the cumulative damage factor for each airplane is obtained by each piece ofsoftware. According to the results obtained from each software design, the pavement thickness and the share ofairplanes from the

amount of cumulative damage are measured. The analyses show that the ability ofFAARFIELD software to design based on three-dimensional finite element method, makes the prediction of thebehavior of airplanes loading on the runway pavement more realistic and designing by this software is moreeconomical.

TOPIC	AUTHOR	DESCRIPTION
Runway design and structural design of an airfield pavement	Sundeep Chowdary Daggubati (et al)	• Design aspects of runway and its structural design. • Computerized system of design is discussed and solutions are arrived in detail. • Runway geometry and orientation along with the structural design of the flexible airfield pavement are obtained.
Finite element modeling of flexible pavement	Sukumaran et.al.	• Finite element analyses techniques to determine the failure mechanism in a pavement system under moving aircraft loads. • Modeling of three-dimensional analysis of pavements.
Transportation Engineering-Airports	Srinivasakumar	• Estimation of design runway length by ICAO.
"Investigation of Runway Pavement Design Software and Determination of Optimization Software"	Ahmad Mansourian et.al	• Five typical pieces of software on the runwaypavement design are evaluated. • Obtain that analysis using FAARFIELD On the runway pavement more realist by this software is moreeconomical.

CHAPTER 3

METHODOLOGY

FIELD VISIT & DATA COLLECTION FROM TRIVANDRUM AIRPORT

FEASIBILITY STUDY

DETAILS COLLECTION FROM CIAL

FEASIBILITY CHECK

GEOMETRIC DESIGN

FAARFIELD

ABAQUS
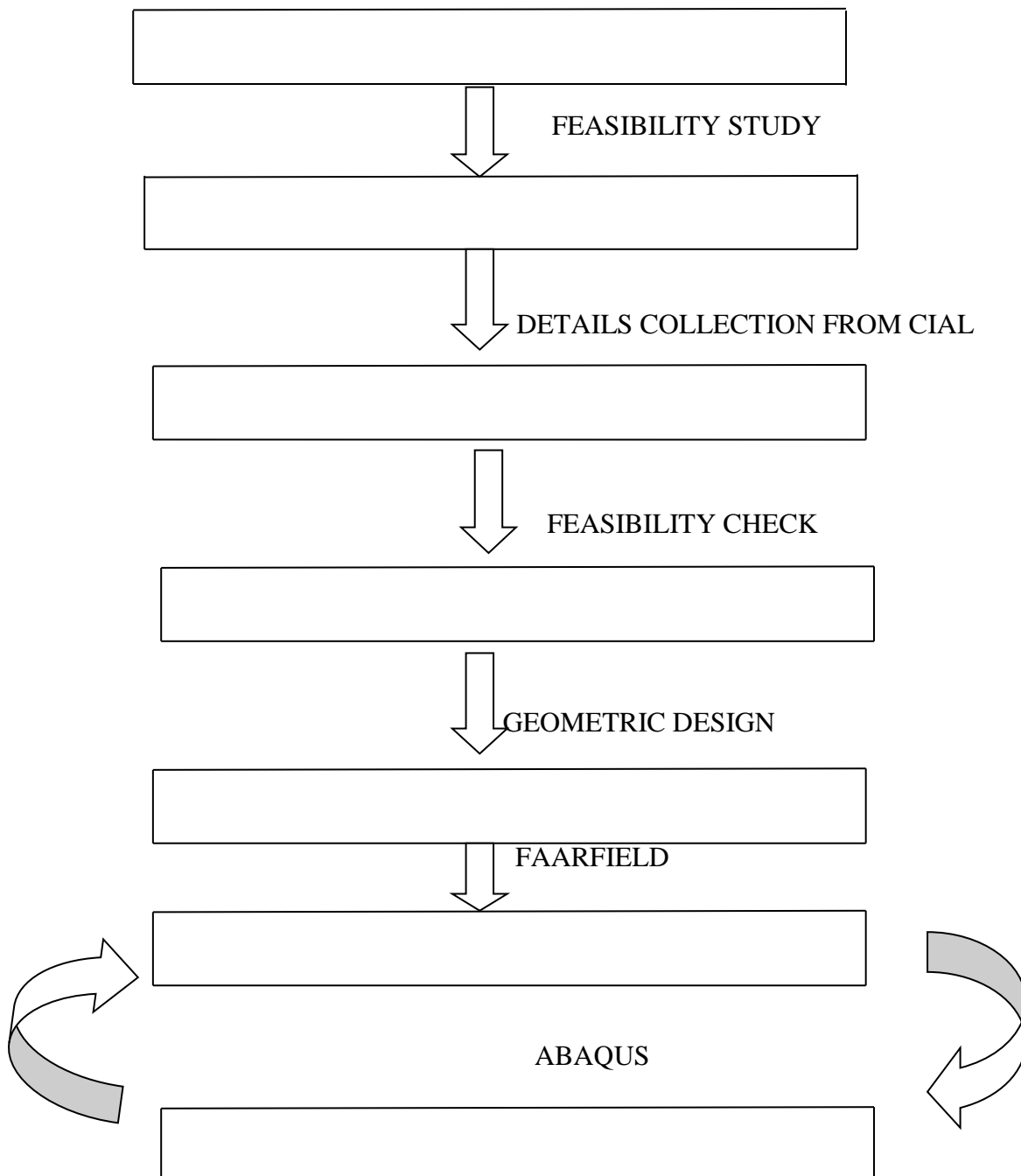
3.1 TRIVANDRUM INTERNATIONAL AIRPORT

Trivandrum International Airport is the first airport in the state of Kerala, India. It was the fifth international airport of India. The airport is a primary base for Air India Express operations and is a focus city for Air India, Jet Airways, SpiceJet and IndiGo.

The Trivandrum International (TRV) airport terminal is approximately 3.7 km (2.3 mi) due west from the city centre, 16 km (9.9 mi) from Kovalam beach, 13 km (8.1 mi) from Technopark, Thiruvananthapuram and 21 km (13 mi) from the under construction Vizhinjam International Seaport spread over an area of 700 acres (280 ha). There are flights to Middle eastern and South eastern countries from here.

Trivandrum International Airport operates two terminals. Terminal 1 handles domestic flight operations (except Air India) and Terminal 2 handles all international flight operations as well as all domestic flights by Air India.

Fig 1: (Source: Google, https://en.wikipedia.org/wiki/Trivandrum International_Airport)

3.1.1 Existing Runway

Trivandrum International Airport has one runway, 3370 m (11155 ft) long and 60m (148 ft) wide (45m pavement and 7.5m shoulder on each side), equipped to operate any type of aircraft in commercial service other

than Airbus A380. The orientation is 32/14. It has a 1,880 m (6,170 ft) long and 44m (ft) wide (23m pavement and 10.5m shoulder on each side) parallel taxiway.

3.1.2 Upgradation of Existing Runway to Code F

Existing Runway is a code E runway with 45m full strength section of pavement. This runway has to be enhanced to accommodate the forecasted traffic at the airport, including the new large Code F Airbus 380. For Code F compliance, the following major works has to be done.

- Widening of full strength pavement from 45m to 60m.
- Additional taxiway links to the runway to provide additional taxi access.
- Runway edge light has to be shifted by 7.5m in accordance with new 60m wide runway.
- Approach lights has to be replaced and sequential flash lights on both ends of the runway should be upgraded.
- New duct banks and AGL circuit has been completed and upgraded toCMS system.
- Navigational aids including localizer and glide pathhas to be shifted.

3.1.3 Feasibility of the work

The existing runway at Trivandrum International Airport has enough strength to accommodate the code F aircrafts. But the dimensions of runway and taxiways and also the clearances between them are to be modified. But there is not enough space in the airport for this expansion. So this proposal can't implement at this airport. So we decided to check the feasibility of this project at Cochin International Airport.

3.2 COCHIN INTERNATIONAL AIRPORT

Cochin International Airport is the first green field airport in the country built with public-private partnership .Planned and constructed from scratch, the airport has been acclaimed for setting a novel idea in infrastructure development. The astonishing public participation, relentless support from NRIs and an effectiveleadership have made CIAL, the company that built and operates the airport, an international brand.

Ever since commercial operations started on 10th June 1999 with International flight to Dammam. CIAL has grown rapidly becoming the 4th largest International Airport in India in terms of international passenger traffic in just four years. CIAL recorded a cumulative annual growth rate of nearly 20% in the initial 8 years and thereafter at 12% with annual passenger traffic touching 7.7 million in 2015-16. The airport handles more than 1100 aircraft movements per week. Over 18 International carriers offer direct flights to the Middle East, Singapore, Malaysia and direct connectivity to UK, Europe, United States, Far East & the Pacific region.

3.2.1 Existing Runway

Cochin International Airport has one runway, 27/09, 3,400 m × 46 m (11,155 ft × 151 ft). It has a full-length parallel taxiway of 3,400 m (11,200 ft). The 807 m × 125 m (2,648 ft × 410 ft) apron comprising 16 stands can accommodate five wide bodied and eight narrow bodied aircraft. The runway is spread over the panchayat areas of Nedumbasserry, Sreemoolanagaram and Kanjoor.
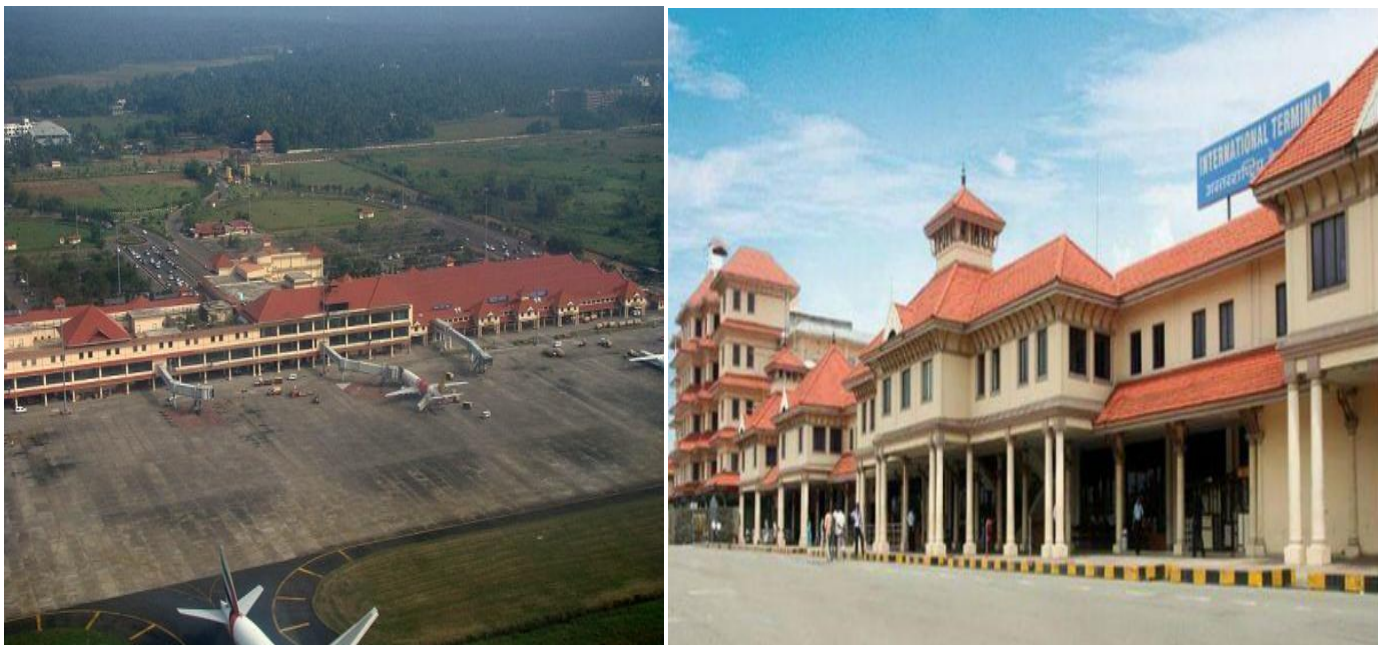

Fig 2: (Source: Google,https://en.wikipedia.org/wiki/Cochin International Airport)

3.2.2 Feasibility of the work

The clearance between the runway and taxiways at this airport is adequate for the accommodation of code F aircraft. But the dimensions of runway and taxiway has to be modified. The airport has sufficient space for the required expansion. So we planned to do our project at this airport.

CHAPTER 4

GEOMETRIC DESIGN

Runways and taxiways should be so planned in relations to other major operating elements such as terminal building, cargo areas, aprons air traffic services and parking etc. to provide an airport configuration offering the maximum overall efficiency. Runways are normally identified by the principal elements.

The proposed parallel runway is a code F runway. The following is the procedure for its geometric design

4.1 Determination of actual runway length

4.1.1 Basic runway length

It is the length of runway under the following assumed condition at the airport:

- Airport altitude is at sea level
- Temperature at the airport is standard (15 C)
- Runway is leveled in the longitudinal direction.
- No wind is blowing on runway
- aircraft is loaded to its full loading capacity
- There is no wind blowing enroute to the destination
- Enroute temperature is standard

According to ICAO the basic length for code F runway is 3000m.

4.1.2 Corrections

Basic runway length is for mean sea level elevation having standard atmospheric conditions. But in actual life, airport may be at any elevation with reference to mean sea level. Also there will be change in atmospheric temperature with reference to assumed standard atmospheric condition. Necessary corrections are therefore required to apply for any change in elevation, temperature and gradient for the actual site of construction.

4.1.3 Corrections for elevation

- As the elevation increases, the air density reduces this inturn reduces the lift on the wings of the aircraft and theaircraft requires greater ground speed before it can rise into the air.
- To achieve greater speed, longer length of runway is required.
- ICAO aerodrome design manual cl. 3.5.2 recommends that the basic runway length should beincrease at rate of 7% per 300m rise in elevation abovemean sea level MSL.
- CIAL is located 9m above mean sea level.
-

Corrections for elevation = Basic runway length * (elevationof airport / 300) *(7/100)

$$=3000*(9/300)*(7/100)$$

$$=6.3m$$

4.1.4 Corrections for temperature

- As the elevation increases, the atmospheric temperatureget reduces.
- Airport reference temperature is defined as the monthlymean of average daily temperature (T_a) for the hottest month of the year plus one third the difference of this temperature(T_a) and the monthly mean of the max. daily temperature (T_m) For same month of the year.

Airport Ref. Temperature (T_a)= $T_a+(T_m-T_a/3)$

- The basic runway length after having been corrected for elevation,should be further increased at the rate of 1% forevery 1C rise of airport reference temperature above thestandard atmospheric temperature at that elevation.
- The temperature gradient of the standard atmosphere is0.0065C per meter.

4.1.5 Check for the total correction for elevation and temperature

- ICAO further recommends that, if the total correctionfor elevation plus temperature exceeds 35% of the basicrunway length, these corrections should then be further checked up by conducting specific studies at the site bymodel tests.

4.1.5 Correction for gradient

- Steeper gradient results in greater consumption of energyand as such longer length of runway are required to attainthe desired ground speed.
- ICAO does not recommend any specific correct for the gradient.

4.2 Requirements of code F runway:

Runway width	60m
Runway shoulder	7.5m
Obstacle free zone	77.5m either side of centre line
Runway holding positions	107.5m from centre line
Taxiway width	25m
Taxiway shoulder	17.5m
Taxiway centre line to Code 4 instrument runway	190m
Taxiway centre line to Code 4 non-instrument runway	115m

To accommodate higher aircrafts, the existing runway should be modified from code E to code F. For this, the dimensions are needs to be changed as per the above mentioned specifications. Also the pavement strength should be increased. The structural redesign of the existing runway is made by using a software called faarfield.
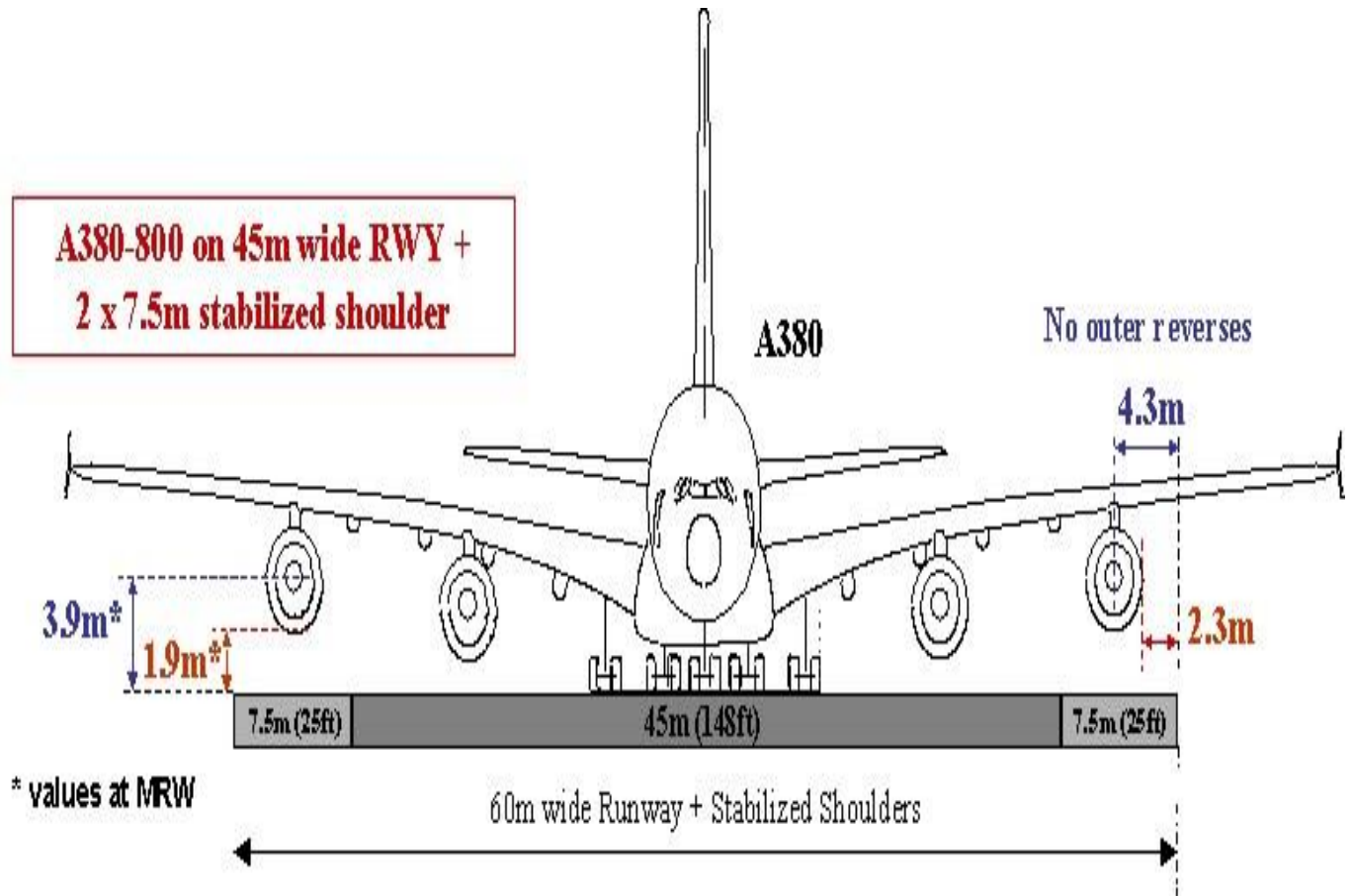
CHAPTER 5

FAARFIELD

Runways require high strength pavements to support the high loads from aircraft movements. Typically, aircraft carry the greatest load when taxiing to the runway for take-off: at this time, the aircraft is laden with passengers and cargo, as well as having full fuel tanks. Conversely, arriving aircraft are lighter as they have consumed fuel during their flight. The runway pavements are designed in consideration of these operational characteristics, the types of aircraft, number of aircraft movements and any specific site requirements. Typically, runways are designed with "flexible pavements" which consist of a gravel pavement with an asphalt surface.

The pavement design is significantly dependant on the aircraft characteristics (wheel loadings and wheel configurations). FAARFIELD, which is the standard design software for airfield pavement thickness, used to determine the preliminary pavement design. It impliments both layerd elastic based and 3D finite element based design procedure developed by federal aviation administration.For new and overlay design of flexible and rigid pavements, design information is entered by means of two graphical screens,one for the structure and one for traffic. Default values are ranges for the various input parameters have been selected.So that the thickness design produced by FAARFIELD are generally compatible with design produced by generation of the FAA design procedure.The main change in the pavement design is that design aeroplane concept is replaced by design for fatigue failure expressed in terms of cdf. The critical aircraft is decidedby considering the PCN and ACN values of pavement and aircraft.The material property of various layeris expressed in terms of elastic modulus and subgrade reaction for rigid pavement. .

5.1 FAARFIELD 1.41

FAARFIELD 1.41 is the standard thickness design software accompanying AC 150/5320-6F Airport Pavement Design and Evaluation. FAARFIELD 1.41 replaces all previous versions of FAARFIELD. FAARFIELD stands for FAA Rigid and Flexible Iterative Elastic Layered Design.It incorporates full 3D finite element responses to aircraft loads (for new rigid pavements and rigid overlays).The 3D finite element models used for rigid pavement designs are computationally intensive and may result in long run times, depending on the computer characteristics.FAARFIELD 1.4 will run on 32- or 64-bit Windows operating systems. At this time, FAARFIELD is not supported on Macintosh.

5.2 Design Of Flexible Pavement Using Faarfield 1.41

STEP 1 Create a New Job
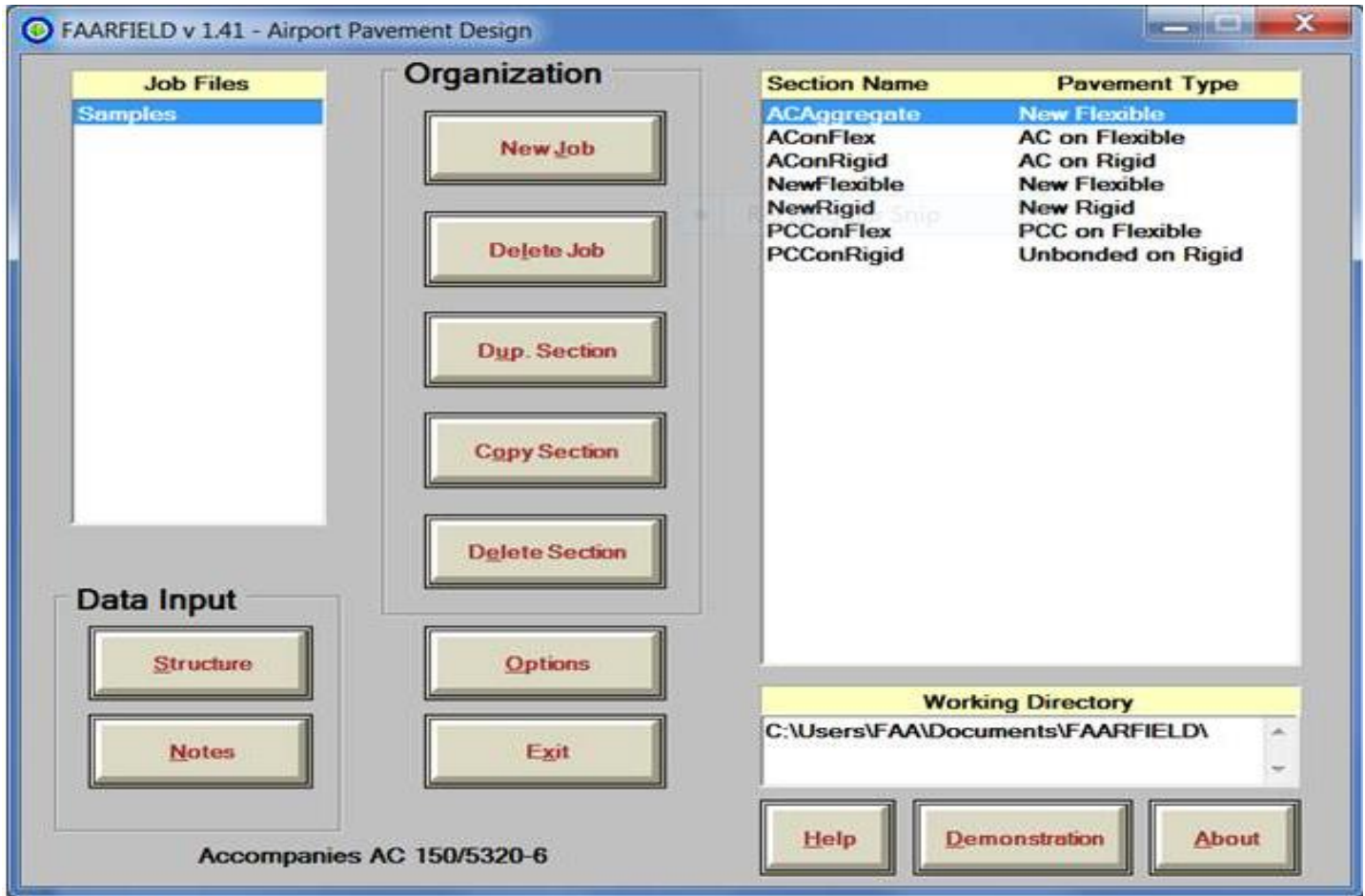
STEP 2

From the right hand window select the type of pavement and select the job.

STEP 3

The "STRUCTURE" window allows a pavement structure to be modified and "designed" to carry the load applied by the selected traffic. On the left of the window is a list of the sections in the current job. On the right of the window is a cross section of the structure showing all layers and displaying the values of all layer properties, both fixed and changeable. Clicking a section name in the list displays the structure corresponding to that name.
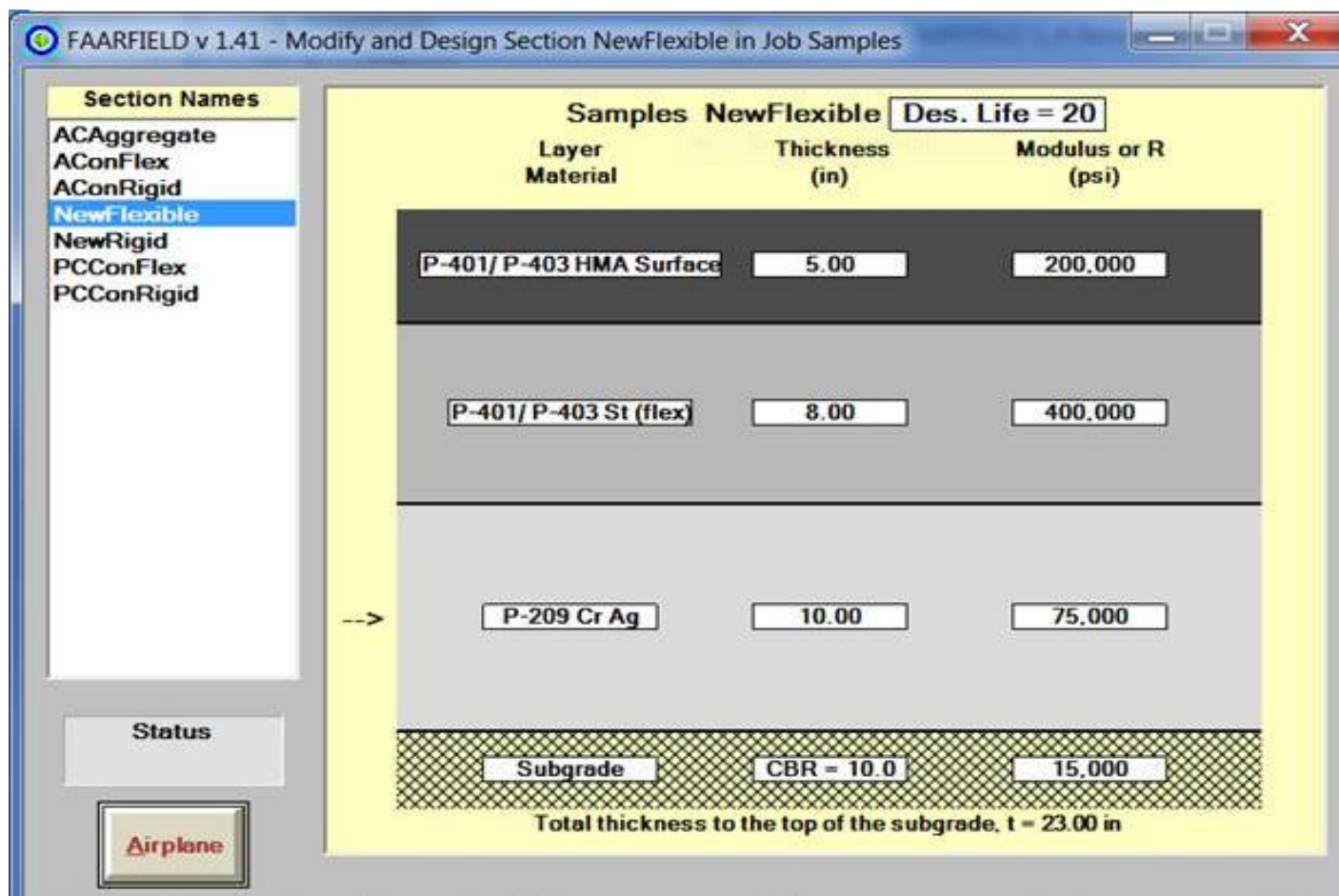
STEP 4

The" AIRPLANE" window allows for the creation and modification of an airplane list for the currently selected section in the currently selected job. Airplanes are selected from the internal airplane library and placed in the design aircraft list on the window provided. The gross taxi weight, number of annual departures, and percent annual growth (defined below) can be changed by the user. Except for these three variables, all other necessary airplane information for design is stored as part of the internal aircraft library and cannot be changed.

At the top left of the Airplane window there is a list of airplane groups. Selecting one of these groups will display all aircraft belonging to that group in the list box below, labeled "Library Airplanes." Currently, the available airplane groups are: Generic, Airbus, Boeing, McDonnell Douglas, Other Commercial, General Aviation, Military and Non-Airplane Vehicles. There is also a category for External Library, which allows the user to define specific aircraft types not found in the internal library, including multiple-gear types.
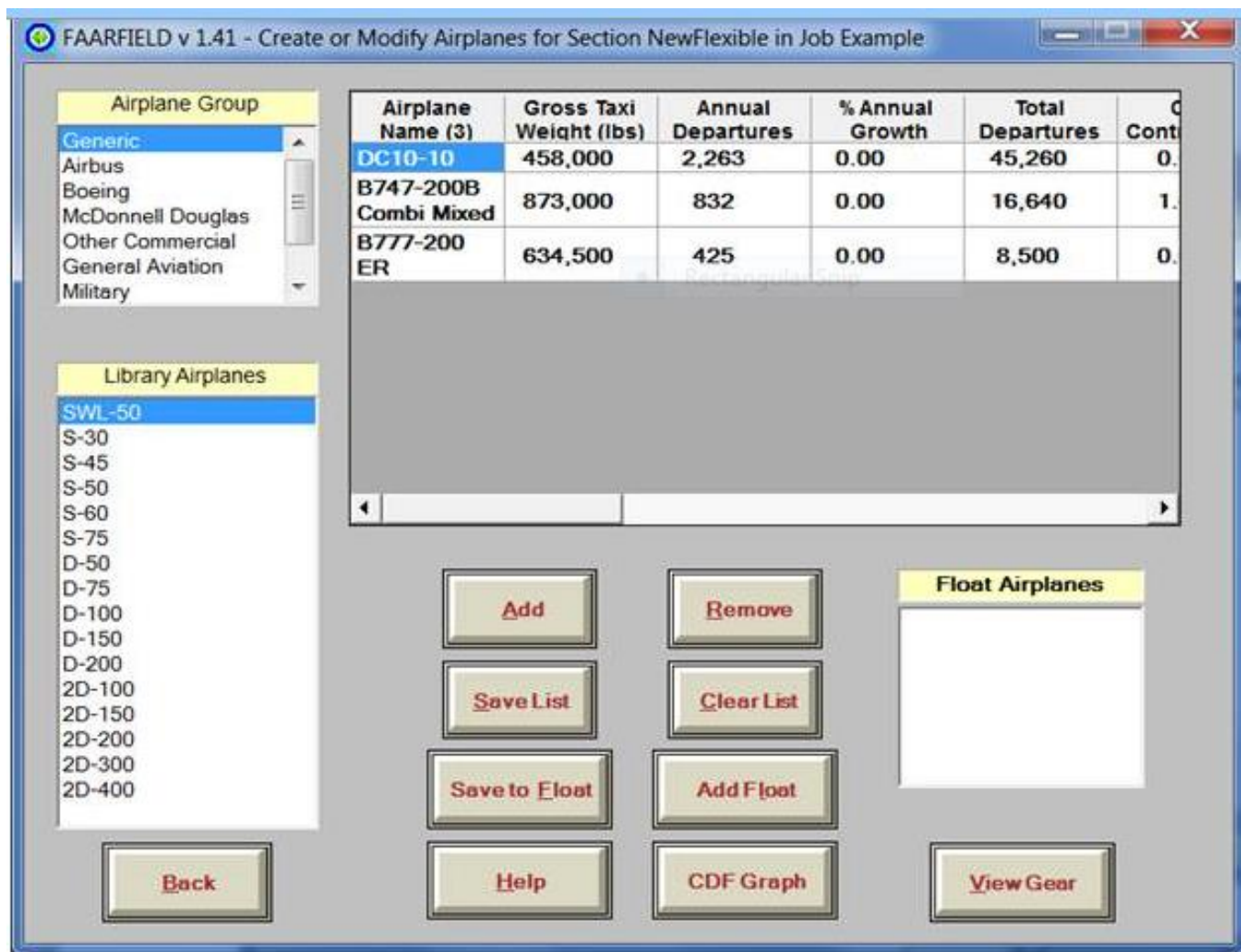
Airplane Window

Transfer an airplane data from the library list to the design list, either select an airplane from the library list then click **Add**, or double click the airplane name in the library list. To remove an airplane, select it from the design list and then **Remove**, or double click the airplane name in the design list.

When an airplane is added to the design list, it will have default values assigned to all fields (gross taxi weight, annual departures, and percent annual growth) can be changed by clicking on the value to be changed. Number of annual departures should be given. For all airplanes in the internal library, the fraction of the gross load carried by the main gear has been set at 95 percent to make the FAARFIELD design procedures. Tire contact lengths and widths are used in the calculation of pass-to-coverage ratio. For this purpose, an elliptical contact patch is assumed, with its area equal to the tire load divided by the tire pressure. (In contrast, circular tire contact patches are used in FAARFIELD to compute layered elastic strain. This is because the layered elastic

model in the LEAF program is axisymmetric)Airplanes with complex landing gear assemblies consisting of separate wing and body gears are treated for design as two separate airplanes: a wing gear airplane and a body gear airplane. A maximum of 40 airplanes can be included in the design list.

Percent annual growth is defined as the percent change in annual departures per year over the design life of the pavement. Negative values represent a decrease in annual departures. The total number of departures for the selected airplane over the design life of the pavement is given by the equation:

$$N = \left(1 + \frac{b \times L}{200}\right) \times a \times L$$

| N	= total departures
L	= pavement design life
A	= initial annual departures
B	= percent annual growth

Large negative percent annual growth can result in negative airplane departures before the end of the design life has been reached. The program automatically detects this condition if it occurs, and assumes zero departures for the airplane from the time at which the departure rate becomes zero to the end of the design life.

To see gear layout of aircraft

Click on "VIEW GEAR". The AIRPLANE DATA window shows the main gear layout for the airplane currently selected in the design list. The gear layout and the tire contact patches are plotted to scale. The image can be copied to the clipboard by clicking the right mouse button. Clicking **Print** causes an image of the Airplane Data Window to be sent to the default printer. The gross taxi weight can also be changed from the Airplane Data Window by clicking the Gross Taxi Weight data display box.

The horizontal locations of the points at which the pavement responses are computed (the evaluation points) are shown in the picture as small black dots.Coordinates of the evaluation points are listed in the output data files.

Mousing over a wheel in the gear footprint image causes the coordinates of the wheel to be displayed.
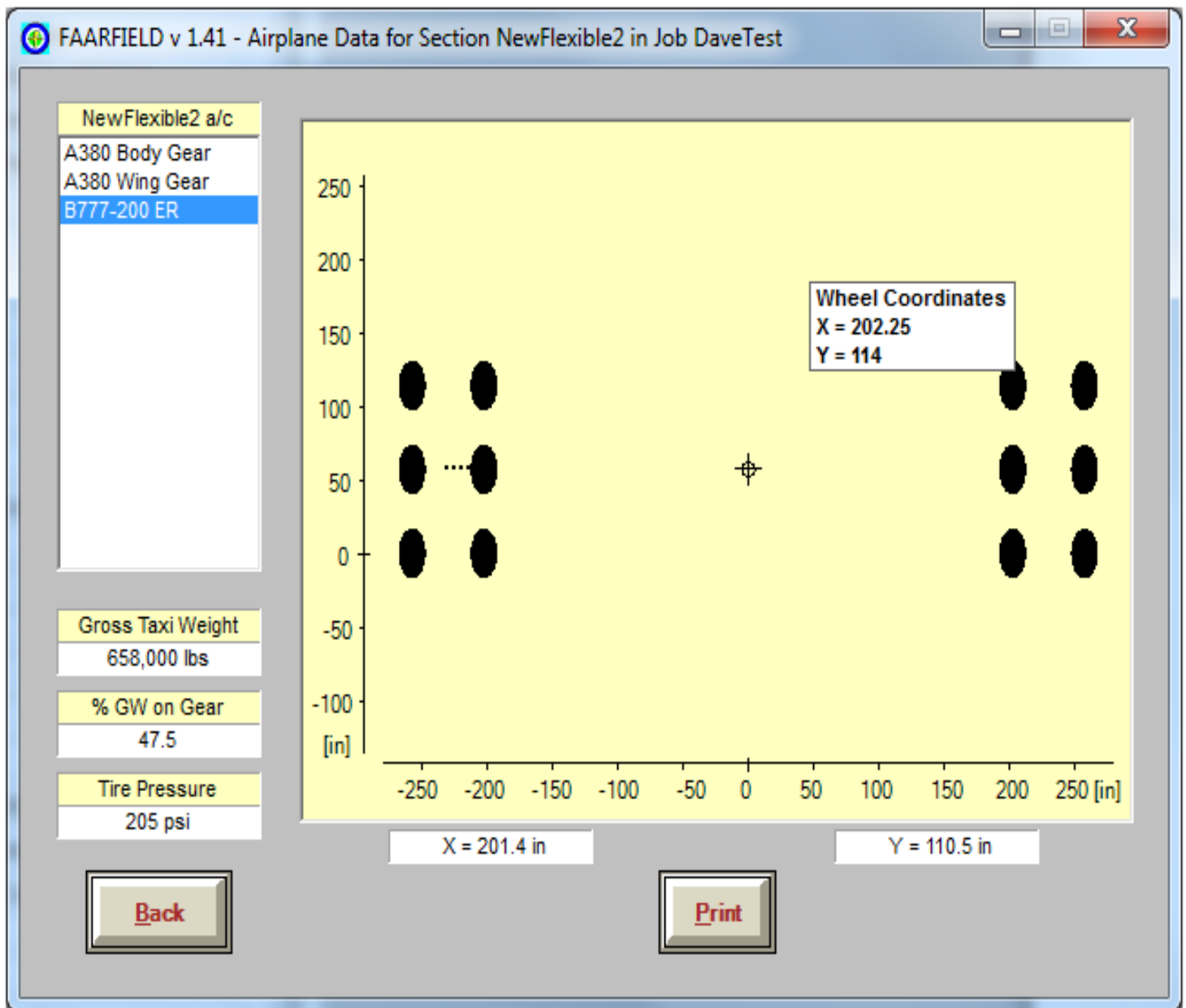
Airplane Landing Gear Data

STEP 5

The "**NOTES**" window is provided for viewing a summary of the design information for the currently selected section and for entering and saving notes on the currently selected section, such as size, location, maintenance history, etc. On the left of the window is a list of the sections in the currently selected job. On the right of the window is a text box which contains either the design information or the notes for the currently selected section.
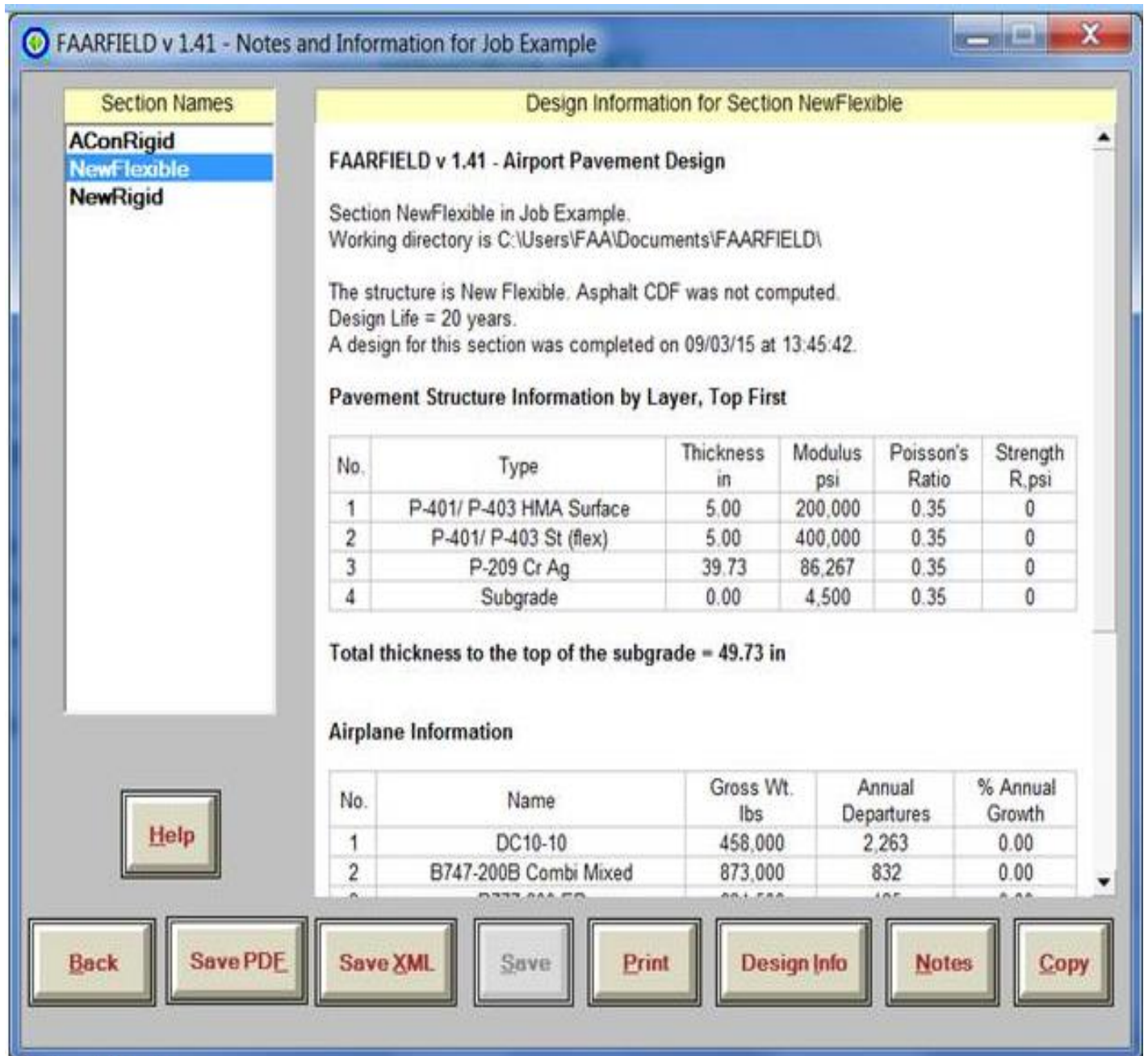
Notes Window

The design is made using cumulative damage factor concept. Cumulative damage factor (*CDF*) is the amount of the structural fatigue life of a pavement that has been used up. It is expressed as the ratio of applied load repetitions to allowable load repetitions to failure, or, for one airplane and constant annual departure.

$$CDF = \frac{\text{number of applied load repetitions}}{\text{number of allowable repetitions to failure}}$$

$$= \frac{(\text{annual departures}) \times (\text{life in years})}{(\text{pass / coverage ratio}) \times (\text{coverages to failure})}$$

$$= \frac{\text{applied coverages}}{\text{coverages to failure}}$$

When $CDF = 1$,	the pavement will have used up all of its fatigue life.
When $CDF < 1$,	the pavement will have some life remaining, and the value of CDF will give the fraction of the life used.
When $CDF > 1$,	all of the fatigue life will have been used up and the pavement will have failed.

In these definitions, failure means failure in a particular structural failure mode according to the assumptions and definitions on which the design procedures are based. A value of *CDF* greater than one does not necessarily mean that the pavement will no longer support traffic, but that it will have failed according to the definition of failure used in the design procedure, and within the constraints of uncertainties in material property assumptions, etc. Nevertheless, the thickness design is based on the assumption that failure occurs when $CDF = 1$.

Multiple airplane types are accounted for by using Miner's Rule:

$$CDF = CDF_1 + CDF_2 + ... CDF_N$$

Where CDF_1 is the *CDF* for each airplane type in the mix and *N* is the number of airplane types in the mix. If the same airplane model operates on a pavement at two or more significantly different weights, each operating weight is treated as a distinct airplane type for the purpose of Miner's rule. FAARFIELD computes a separate *CDF* for each failure mode included in the design procedure. The thickness is adjusted to make the *CDF* for subgrade failure equal to 1. An additional computation is then made to find the *CDF* for asphalt fatigue cracking. If the asphalt *CDF* is found to be less than 1, the asphalt is predicted not to fail in cracking before the

subgrade fails. But if the asphalt *CDF* is greater than 1, the asphalt is predicted to fail before the subgrade, and adjustments should be made to base and subbase layers so that asphalt *CDF* is less than 1 in the final design.

Execution time is roughly proportional to the total number of "design" wheels for all of the airplanes in the design list, and is proportional to a small power of the number of layers in the structure.

CHAPTER 6

ABAQUES

Introduction of Fea and Abaqus

FEA is the abbreviation of Finite Element Analysis. Generally, engineering analysis can be classified into two types: Classic method and Numerical method. FEA is a numericalmethod for solving partial differential equation as well as integral equations generatedfrom complex structure. It was originated from the need of solving complex elasticity and structural analysis problems in Civil, Mechanical and Aerospace engineering. In a structural simulation, FEA helps in producing stiffness and strength visualizations. FEA allows for detailed visualization and indicates the distribution of stresses and strains inside the body of a structure. Many of FEA software are powerful yet complex tool meant for professional engineers with the training and education necessary to properly interpret the results. This powerful design tool has significantly improved both the standard of engineering designs and the methodology of the design process in many applications.

4.6 Concepts of Elements and Nodes

Any continuum/domain can be divided into a number of pieces with very small dimensions. These small pieces of finite dimension are called 'Finite Elements' (Fig.). A field quantity in each element is allowed to have a simple spatial variation which can be described by polynomial terms. Thus the original domain is considered as an assemblage of number of such small elements.These elements are connected through number of joints which are called 'Nodes'. While discretizing the structural system, it is assumed that the elements are attached to the adjacent elements only at the nodal points. Each element contains the material and geometrical properties. The material properties inside an element are assumed to be constant. The elements may be 1D elements, 2D elements or 3D elements. The physical object can be modeled by choosing appropriate element such as frame element, plate element, shell element, solid element, etc. All elements are then assembled to obtain the solution of the entire domain/structure under certain loading conditions. Nodes are assigned at a certain density throughout the continuum depending on the anticipated stress levels of a particular domain. Regions which will receive large amounts of stress variation usually have a higher node density than those which experience little or no stress.

4.7 Pavement Analysis For Aircraft Load Using Abaqus

4.7.1 General Finite element analysis procedure

General Finite Element Analysis Procedure includes the following three steps which alsoconstruct the main framework of available FEA software.

1. Preprocessing: in this step, the user constructed model is divided (meshed) into a number of discrete subregions or "elements", connected at discrete nodes. Certain boundary conditions are applied to some of the nodes in displacement or load. In one word, after preprocessing of FEA, the finite element model should be ready for being submitted to the solution.

2. Solution/Analysis: in this step, the finite element model is submitted to the solver as input in finite element code. A series of linear or nonlinear equations will be solved to generate numerical output of displacement, stress etc on nodes.

4.7.2 Abaqus As Finite Element Software

ABAQUS, a commercial finite element modeling program, has been widely applied for pavement analysis. Chen et al did a comprehensive study of various pavement analysis programs and showed that the results from ABAQUS program were comparable to those from other programs. Zaghloul and White simulated the pavement responses under FWD loading for flexible pavements using three dimensional dynamic analysis in ABAQUS. ABAQUS provides many element types that are useful for pavement analysis.

An infinite element model can be used to model the infinite boundary conditions in the horizontal and vertical directions in a pavement system. ABAQUS also includes many material models such as linear elastic, viscoelastic, hypoelastic and elastoplastic models. Finite element method calculates the values of stresses and strains by node to node lumping of loads. So, appropriate element selection and meshing is also very important.

4.7.3 Two Dimensional, Axis-Symmetric Finite Element Model

A two dimensional axisymmetric model was primarily developed in order to establish a theoretical validation of the model assumptions with the Boussinesq theory. The model was then analysed in ABAQUS and the vertical stress developed was compared with the Boussinesq theory. The model details are listed below.

4.7.3.1 Material Characterization

Assuming a single layer of material pavement materials were assumed to respond linearly and elastically to the applied load as static load were applied in the linear perturbation step. Elastic properties (modulus of elasticity and Poisson's ratio) were obtained from previous investigation (Zaghloul and White, 1993). Some random   material properties were also given to understand the response under different condition. Since the material was modelled to be axis symmetric, in order to obtain a circular loading, a loading of magnitude 800N and a radius of 0.5m was modelled

4.7.3.2 Model Dimensions and Element Type
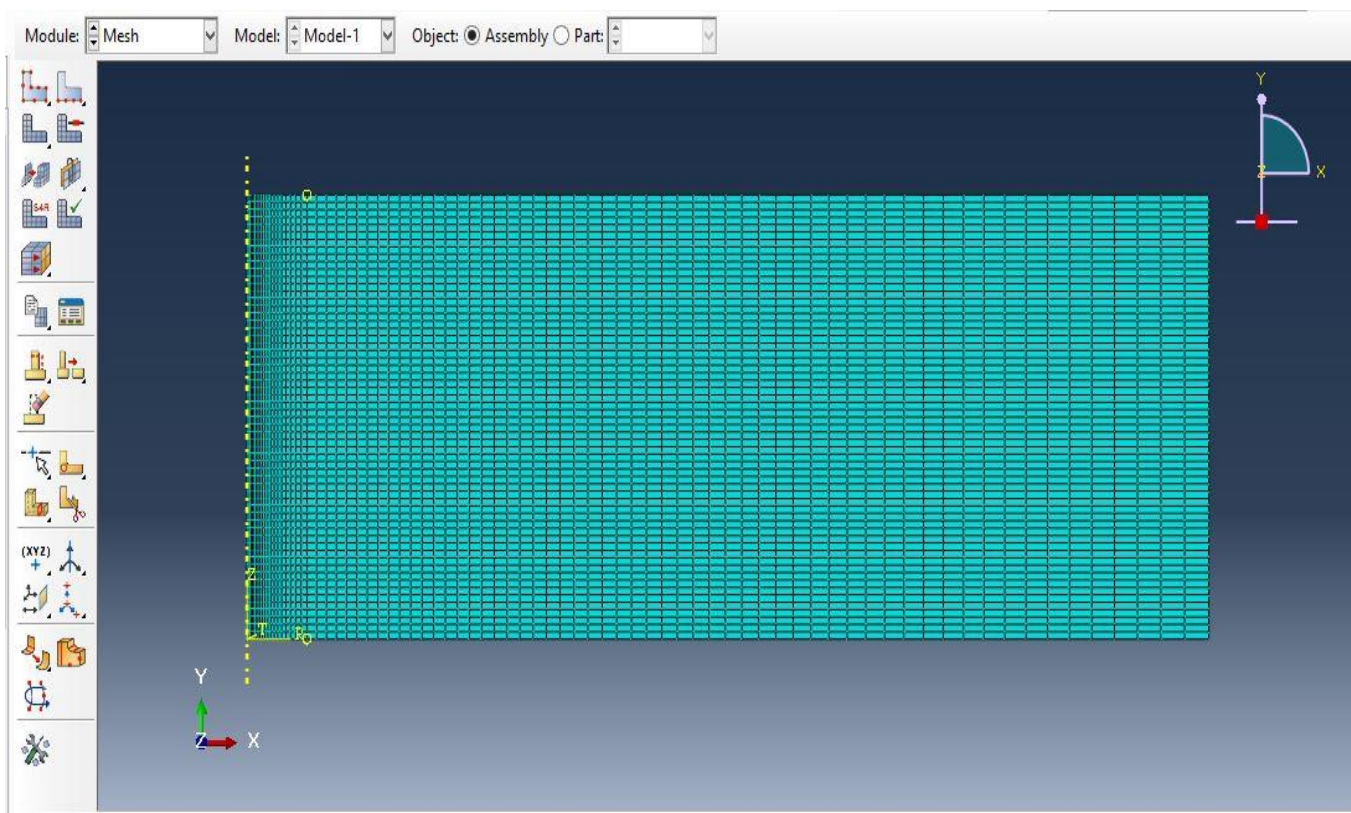
Fig 8: Model dimensions and element type

Model dimensions were selected to reduce any edge effect errors, while keeping the elements sizes within acceptable limits (modelling constraints). After a trial of 2-3 models, the generated structured mesh (0.01-1 mm) was designed to give an optimal accuracy (small elements around the load and large elements

away from it). All layers were simulated with the same shape to preserve the continuity of nodes between consecutive layers. More elements are used around the loads where stresses and displacement gradients are higher.
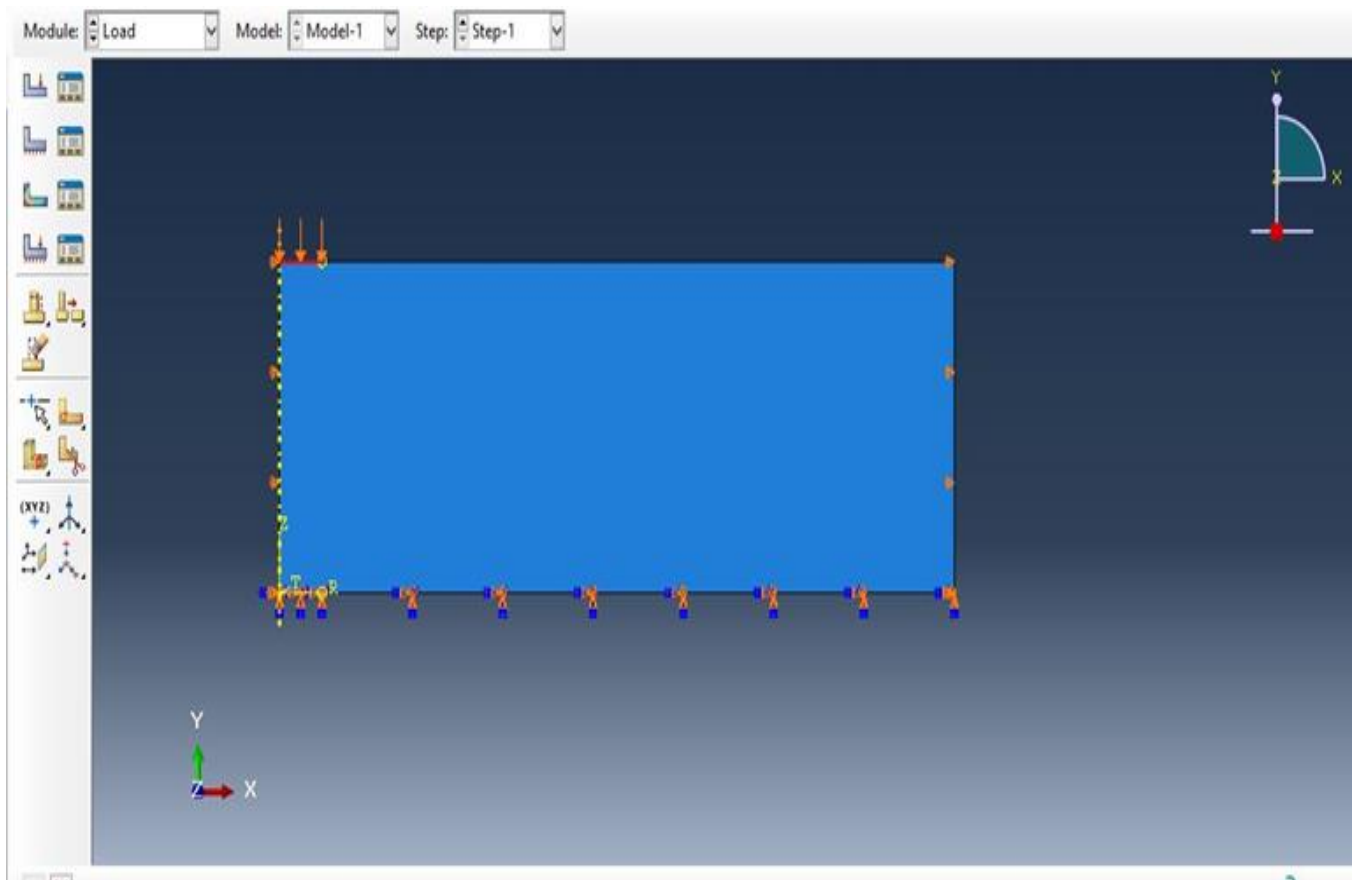
4.7.3.4 Boundary and Contact Modelling

Fig 9: Boundary and Contact Modelling

Horizontal displacement constraints applied at the sides of the model to simulate the lateral support of the pavement structure. The boundary condition at the bottom of the model was assumed to be fixed (ENASTRE) in order to simulate the infinite extending layer concept in Boussinesq theory.

4.7.4 Evaluation of Stress Strain Characteristics

Finite element software, ABAQUS is used effectively in measuring vertical stress and deflections under the application of static load in the modelled structure. Though critical model dimension, appropriate element type, meshing strategy, boundary condition significantly affect the results using software; the variation of strain value is observed for a specific modelled structure for different values of modulus of elasticity of the material. The stress contour obtained from this study is shown in Figure.
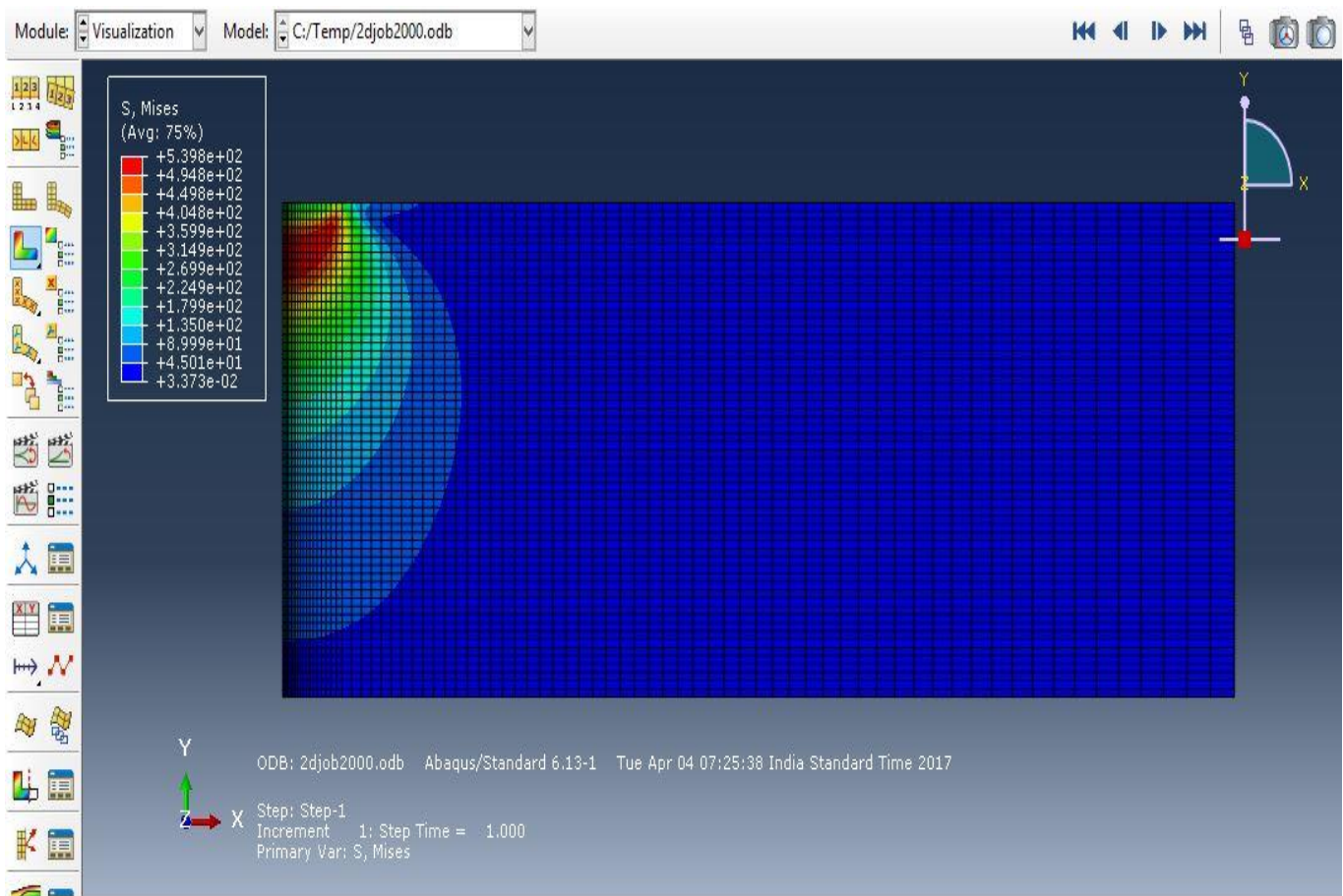

Figure 10: Stress contour obtained for a 2D axis symmetric model subjected to circular loading.

From the figure, it can be seen that lowest value stress is found at the bottom most

pointand maximum stress occures within the materialunder the load application area.The deformed shape of the material is depicted in figure to a scale factor.
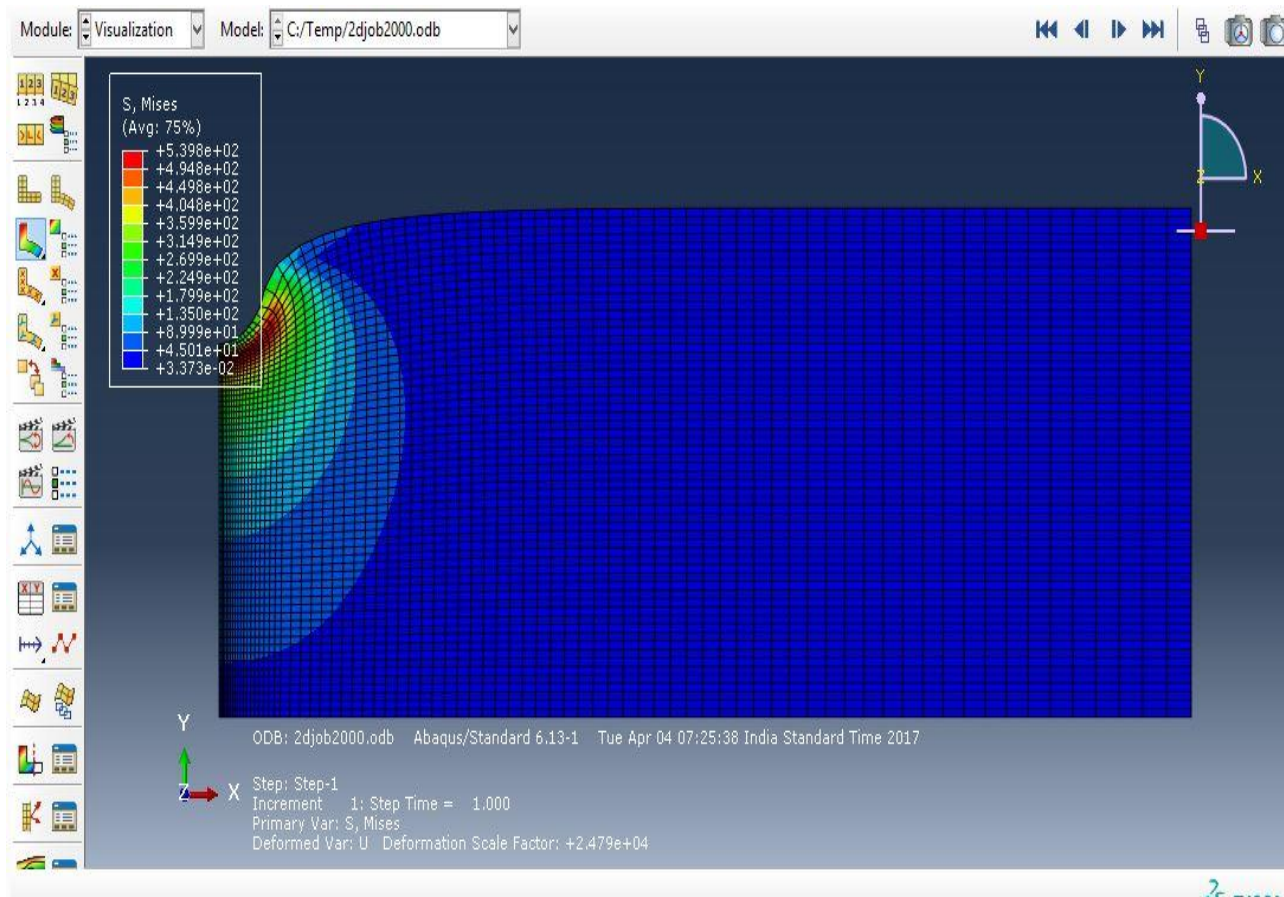
Fig 11: Evaluation of Stress Strain Characteristics

4.7.5 Theoretical Validation Of The Model With The Boussinesq Theory

The vertical stress (σ_Z) on the axis of a circular area loaded by a uniform vertical loading q is given by

$$\sigma_Z = q \left[1 - \left\{ \frac{1}{1 + (a/z)^2} \right\}^{3/2} \right]$$

A plot between vertical stress and depth was developed in excel using the Boussinesq equation for circular loading. The plot obtained by analysis using ABAQUS was compared with the plot given by Boussinesq equation and the model was validated thereby.
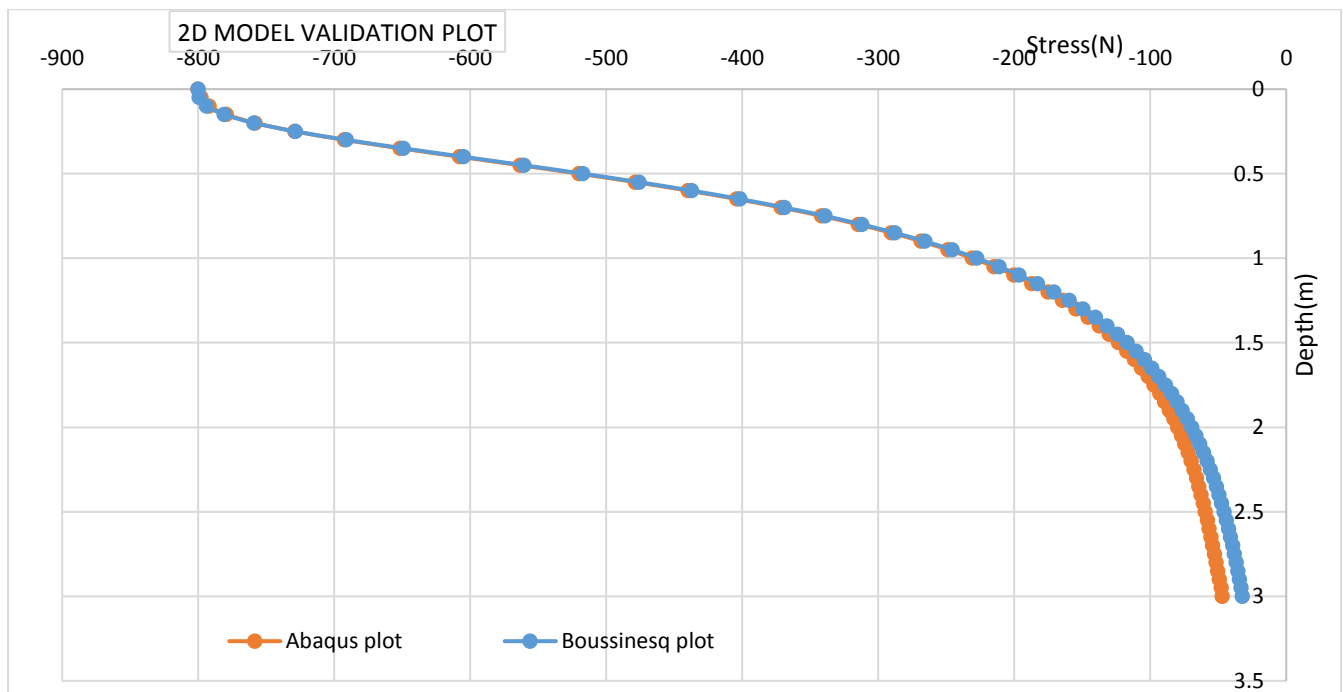
Chart 1. 2d Model Validation Plot

4.7.5.1 RESULTS

The model was analysed to plot the vertical stress vs. depth, deflection vs. depth, and vertical stress vs. horizontal distance for three modulus of elasticity values. From the graph we get a clear inference on the influence of the property of a material (modulus of elasticity) on the vertical stress and deflections induced due to an external loading on a sample model.
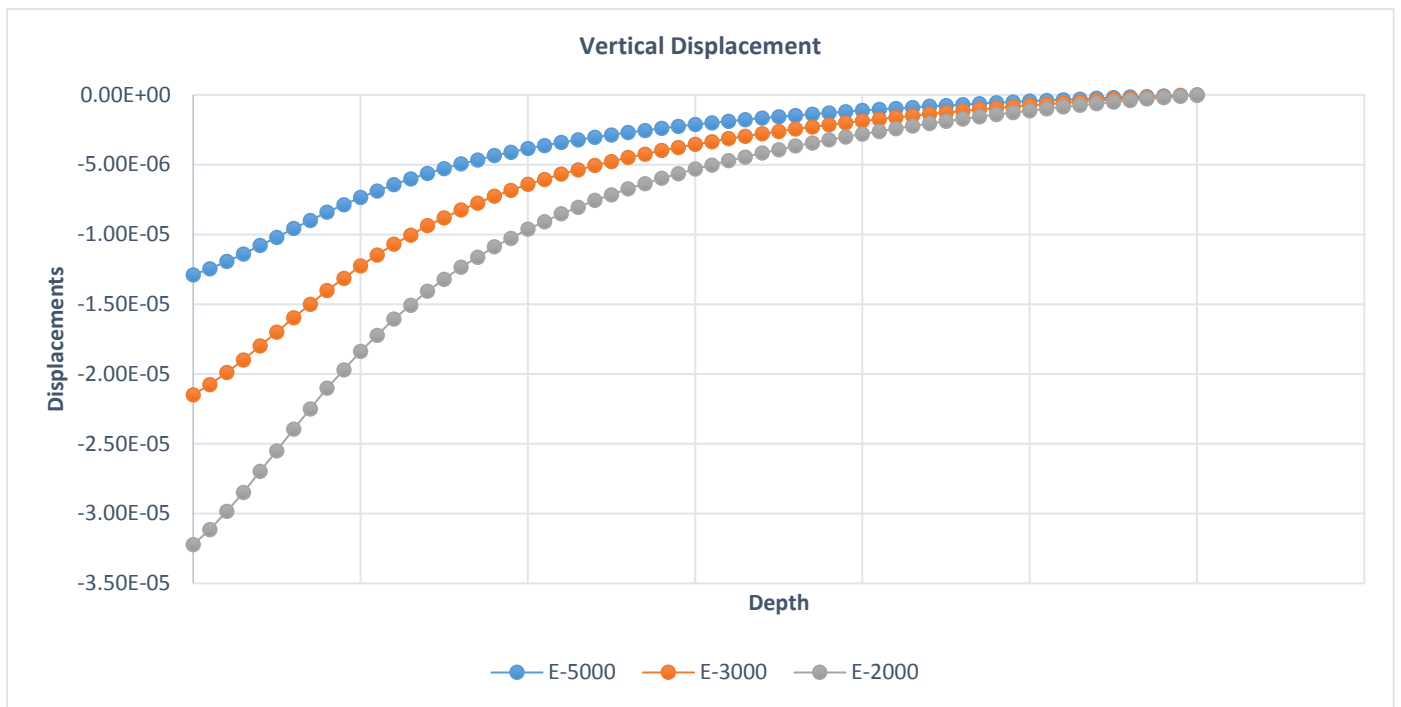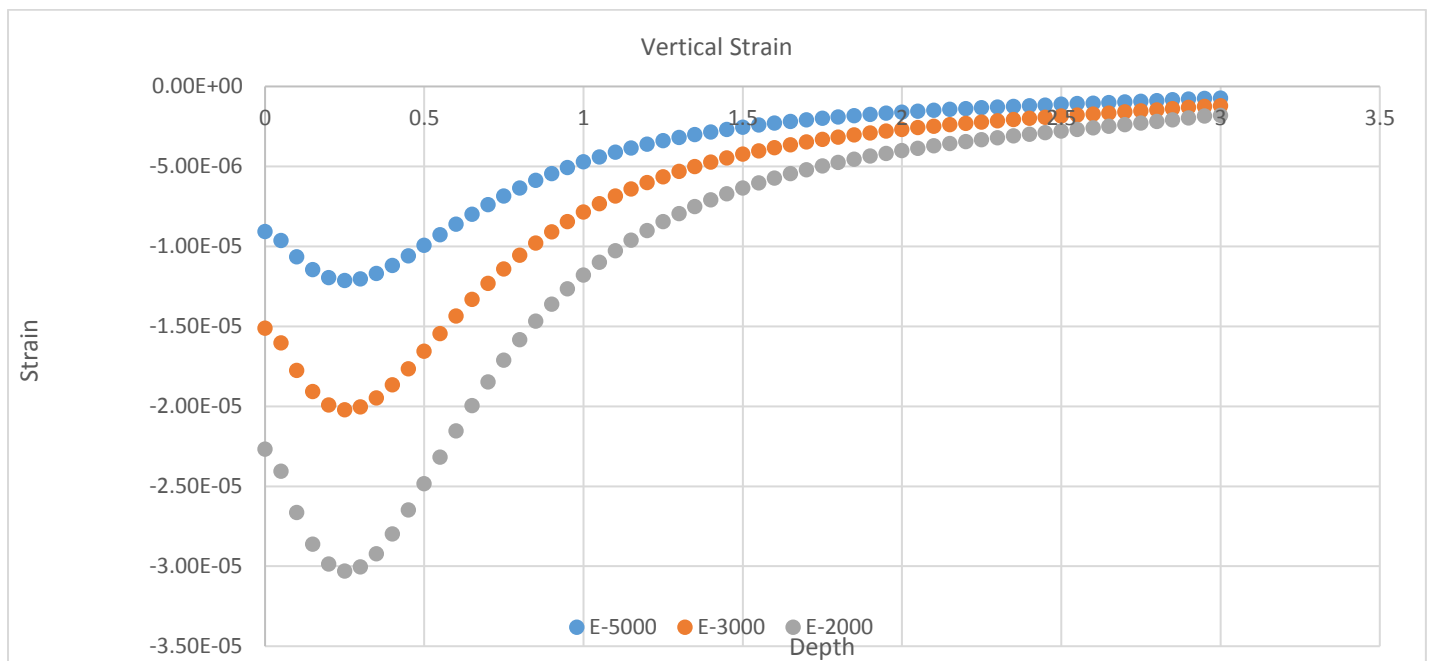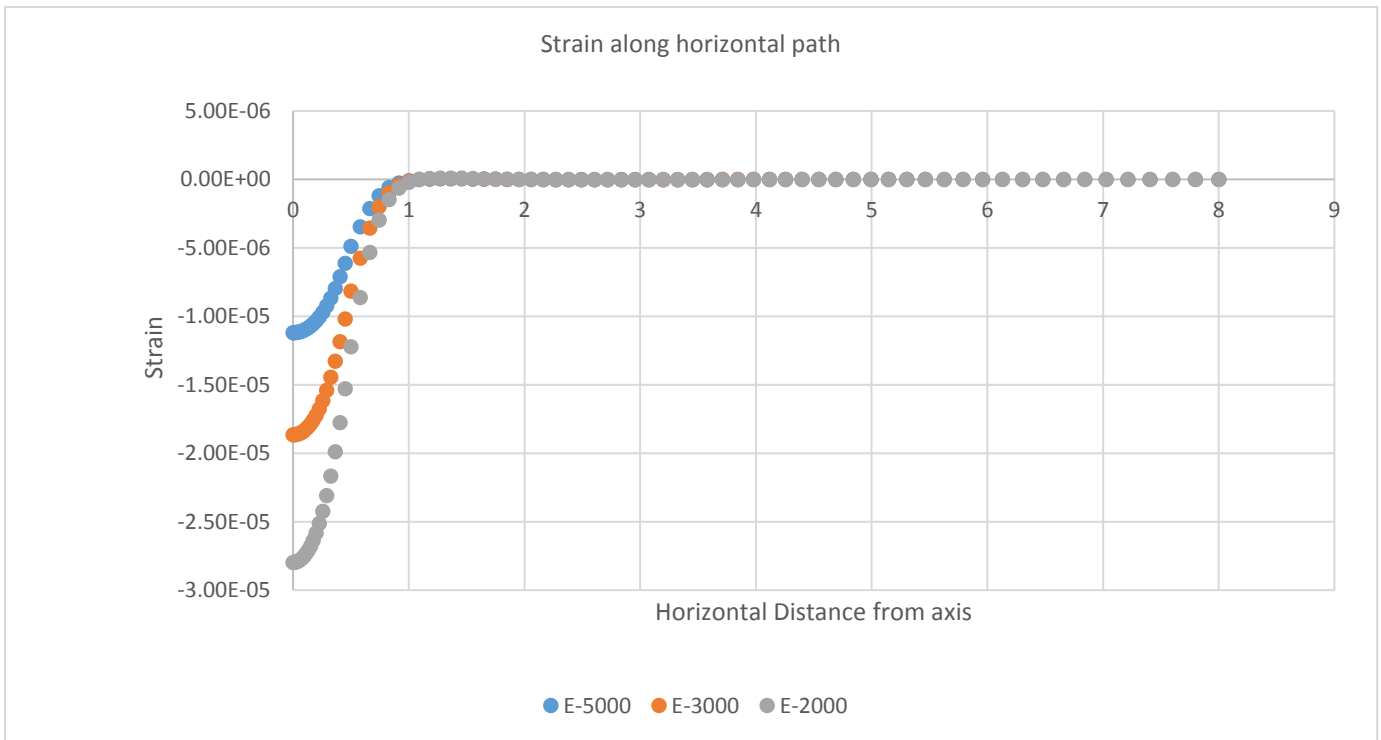
Chart 2: Vertical Displacement

Chart 3: Vertical Strain

Chart 4: Strain Along Horizontal Path