ANALYSIS OF BOX CULVERT WITH AND WITHOUT HAUNCHES

A thesis

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

IN

CIVIL ENGINEERING

With specialization in

STRUCTURAL ENGINEERING

Under the supervision of

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To

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HIMACHAL PRADESH, INDIA

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CERTIFICATE

This is to certify that the work which is being presented in this project report titled **“ANALYSIS OF BOX CULVERT WITH AND WITHOUT HAUNCHES”** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in **“Structural Engineering”** and submitted to the Department of Civil Engineering, Jaypee University Of Information Technology, Waknaghat is an authentic record of work carried out by **Ishaan Pandey (152652)** during a period from June 2017 to May 2017 under the supervision of **Mr. Saurav**, Assistant Professor, Department of Civil Engineering, Jaypee University Of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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Abstract

Recent developments in computer technology have made it possible the use of Finite Element methods for 3D modeling and analysis of reinforced concrete structures. Several works have already been done on Finite Element analysis of Box Culverts. In the past study of box culverts, effect of haunch has not been considered in reduction of flexural stresses. In this study Finite Element analysis of Box Culverts is carried out with ANSYS software which is a computer based analysis tool on Finite Element Method. In this study a Box Culvert of clear inside dimensions 6m×6m and thickness of slabs and side walls as 0.5m has been used. Modeling is done with plain cement concrete by giving two basic properties viz. modulus of elasticity and poisons ratio. Modeling with these properties gives exact stresses which are likely to develop after loading. First a Box Culvert is modeled without providing haunch or chamfer and later it is analyzed by providing haunch of varying size viz. 0.5, 1.0, 1.5, 2.0 times thickness of wall. After analysis of these models in ANSYS, results of stresses, deflection has been taken from post processing mode to carry out comparative study between five cases. Also graphs have been plotted to see variation of flexural stresses in different models to get Bending Moments. Finally with the help of these Bending Moments exact thickness and reinforcement required is carried in all the models and finally comparative quantity and cost study between these has been presented. At the end, a comparative study of conventional method and finite element method is carried out in two computer aided programs namely STAADPro and ANSYS 14.5 which shows huge difference in deflection, shear stress and equivalent stress in the same structure.

Chapter 1

INTRODUCTION

1.1 General

In this study a Box Culvert of clear inside dimensions 6m×6m and thickness of slabs and side walls as 0.5m has been used. Modeling is done with plain cement concrete by giving two basic properties viz. modulus of elasticity and poisons ratio. Modeling with these properties gives exact stresses which are likely to develop after loading. First a Box Culvert is modeled without providing haunch and later it is analyzed by providing haunch of varying size viz. 0.5T, 1T, 1.5T, 2T etc. where ‘T’ is thickness of wall. After analysis of these models in ANSYS, results of stresses, deflection has been taken from post processing mode to carry out comparative study. Also graphs has been plotted to see variation of flexural stresses in different models to get Bending Moments. Finally with the help of these Bending Moments exact thickness and reinforcement required is carried in all the models and finally comparative study between them has been done.

1.2 Introduction To Culverts

A culvert is a structure that conveys surface water across a railway, roadway, or other crossings when the flow comes in between. In addition to the above function, a culvert carries various loads such as hydraulic loads, railroads, roadways, construction and earth loads. Hence, the design of culverts involves both structural as well as hydraulic design consideration. In this project effect of both has been considered for the analysis.

Culverts are constructed into many shapes, sizes and different methods and materials. Different combinations of factors affect the capacity and performance of culverts. Its size can be varied from a small rectangular or square to large arch, depending on the requirements, as per the cost and effectiveness of the project.

Most common shape that has been employed is circular but box shape and arch shape are also used commonly. The other shapes like rectangular and elliptical are used over circular when there is limited surface cover. Box culverts are used where there flow is low to medium and bearing capacity of soil is low. They can be designed for almost any cross section and can satisfy any site condition. The aspect ratio can also be easily changed as per the requirements.

Construction material that are used for culverts are dependent on the desired properties such as durability, abrasion due to running water, strength, roughness, bedding conditions and corrosion of the material. The most commonly used material is steel reinforced concrete.

Inlet configuration of culverts is also an important factor that affects it performance. The inlet of culvert may consist of a culvert barrel stretching from the earth roadway fill or joined to the slope of embankment. Other inlets may have headwalls, apron slab or wing walls and other standard concrete or metals sections.

1.3 Box Culverts

Box culvert is the most economical amongst all types of culverts and superior in conveying desired requirements. It is laid without any PCC for foundation as the monolithic structure; the bottom slab serves as the raft foundation for the culverts. They are used where the soil bearing strength is low and the water head is also not so large. If the span is more, they can be used as multi-celled box culvert. The box culverts are made by method of pre-stressing and can be easily placed on the site.

The project includes the FEM analysis showing importance of width of haunches by placing uniformly distributed load all along its four sides acting inside and the results are analyzed.

1.4 Objective Of The Project

i) Economical effect of thickness of haunches in box culverts.

ii) Comparative study STAAD and ANSYS software, i.e. conventional method and FEM

Chapter 2

LITERATURE REVIEW

2.1 General

There are several researches already have been done on behavior of RC box culverts in past with different conditions of loads. The design and analysis of box culverts is a complex task. Although the present era offers the finite element analysis of 3D model of structures. The effect of haunches in reducing shear has yet not been considered. This report represents the complete 3D modeling and analysis of box culvert using ANSYS software showing haunches useful in reducing the shear and making it economic for the culvert.

2.2 Analysis of Box Culvert under Cushion Loading by A.A. Galatage A.D. Patil A.D. Patil[1]

The report represents the box culverts made in reinforced concrete having different aspect ratios. The box culverts are analyzed for different cushion and no cushion loading. The main importance is given to behavior of the box culvert under the types of loading according to IRC codes and the various combinations that produce worst effect for safe structural design. The study shows that the load combinations with empty box are found to be the critical combination for all values of aspect ratios under consideration. Bending moments for aspect ratios 1 and 1.5 are found to be different and for aspect ratio 2 and 3 are found to be constant for all load combinations, with and without cushion. The effect of soil pressure and water pressure is considerable for aspect ratio 1 and 1.5 and negligible for aspect ratios 2 and 3

2.3 Chamfer in Box Culverts by K.S.V Prasanth Harshad Birajdar Dr. P. K Singh[2]

In the design of box culverts conventional procedures are being followed. Though chamfer is being provided at corners but it is not accounted in the structural design. In the present paper an effort has been made to present a new economical approach for design of box culverts with chamfer in flexure and shear. Also, the corners of box culvert with varying chamfer sizes have been analyzed by FEM analysis using ANSYS software.

The analysis depicts that overall stress level decreases with increase in chamfer size. When the thickness of chamfer is twice the thickness of wall maximum compressive stress is reduced by 68% and maximum tensile stress is reduced by 60%. By including diagonal reinforcement along with the loops, increases joint efficiency by 42%. Unlike the conventional design where maximum negative moment is considered as design moment, the maximum positive moment can be considered as design moment for box culverts with chamfer size equal to 1.5 times thickness of framing member. In case of high concentrated loads or loadings in which shear force is critical, the unsymmetrical chamfer of appropriate size can be provided in areas of high shear stress to obviate the shear reinforcement.

2.4 Comparison and Study of Different Aspect Ratio of Box Culvert by Shraddha Sharma and Ketan Kishor Sahu[3]

This Paper shows that box culverts constructed in RCC having one, two or three cells and varies their operating conditions and analysis for their design. The cost by considering optimum thickness and without considering optimum thickness was compared. Accordingly, results are presented that justifies that optimum thickness presented over here leads to economical design of culverts. An attempt is made to generate the comparative charts for bending moments for top and bottom members. Such that from these charts at any intermediate aspect ratio the values of bending moments can be evaluated.

The study showed that the L by H aspect ratio of 4/3 and 4/2 has less end moments value and more maximum bending moment compared to L by H aspect ratio of 4/4. The box culvert of L/H aspect ratio of 4/2 will be more economical since the percentage saving will be more in velocity, hydraulic mean depth, depth of water, perimeter, area volume of concrete and the end moments value will be less as on top slab, bottom slab, vertical side wall portion as well as the maximum bending moment of this section will be safer, compared to other sections

2.5 Design coefficients for Single and Two cell box culvert by R. Shreedhar Sujata Shreedhar[4]

Multi-celled reinforced box culverts are ideal structure if the discharge in a drain crossing the road is not large and if the bearing capacity of the soil is low as the single-celled box culvert are not economical because of the higher thickness of the slab and side walls. It is very hard for the designer to arrive at the decision for coefficient for moments, shear forces and axial thrusts for different loading cases and for different ratios of L/H for multiple cell box culverts by using classical methods such as moment distribution methods, slope deflection method etc. Thus, design coefficients are helpful for designers to decide the combination of various loading cases to arrive at the critical design forces at the critical section, saving time and effort.

The results of the study showed that the critical section considered is at the centre of span of top and bottom slabs and the support sections and at the centre of the vertical walls since the maximum design forces that are developed at these sections due to different combinations for loading patterns. The maximum positive moments at the centre of top and bottom slab for the condition that the sides of the culvert not carrying the LL and the culvert is running full of water. The critical negative moment develops at the support sections of the bottom slab for the condition that the culvert is empty and the top slab carries the dead load and live load. The multi celled box culverts are economical for larger spans compared to single cell box culverts as the maximum bending moment and shear force values decreases considerably, thus requiring thinner sections.

2.6 Delayed Shear Crack Formation of Shallow RC Box Culverts in Service by N Chijiwa[5]

The study shows the effect of long term loads on the culverts in service. It presents the large deformation of the underground RC culverts that has been monitored for 20 years and analytically discussed further. It accompanies the synergy effects on the culverts in service for long that may fail due to formation of shear cracks at later stages of life in culverts that are experiencing vertical soil pressure and are exposed to creep and shrinkage that are time dependent. The delayed cracks are then experimentally developed in laboratory and multi scaled simulation is done.

2.7 Finite-Element Modelling and Analysis of Reinforced Concrete Box Culverts by Garg A. K. and Abolmaali A.[6]

This study shows the creation of an analytical program to calculate the shear capacity of precast RCC box culverts. To simulate the calculated results, complete and detailed 3D finite-element models (FEMs) of the test specimens were developed and analyzed. Three-dimensional shell and solid elements were used to model the culvert systems. The welded wire fabrics are modelled by using the reinforcement bars elements placed on the surface elements given by the ABAQUS software. The contact surface between the outer face of the bottom slab and reaction floor was modelled by using the nonlinear node-to-surface contact analysis procedure. The analysis procedure contains san increasing loading history to capture the problem of nonlinearity. The load was put at a particular distance from the tip edge of the haunch of the box culvert, where the particular distance is the effective depth of tension reinforcement at mid span, in the top slab of the box culvert. To analyse the wheel load a 25.4 cm (10 in.) ×51 cm (20 in.) plate is used experimentally as well as in FEM, which is used by AASHTO to model the wheel load of a HS20 truck. The smeared crack model along with the Risk analysis procedure was included to analyze the system for micro cracks and to stabilize the results, respectively. The converged solution was obtained by using *H* convergence coupled with the difference between the external work done and the strain energy density of the system. The load-deflection plots obtained from the FEM analyses were compared with those obtained from the experimental results, which showed close correlation.

2.8 Shear Behaviour and Mode of Failure for ASTM C1433 Precast Box Culverts by Anil K. Garg and Ali Abolmaali[7].

This study evaluates the shear behaviour and capacity of the precast concrete box culverts subjected to HS 20 truck wheel load. The most critical culvert behaviour was considered by studying culverts subjected to zero depth of the fill and placed on a rigid bedding material. Full-scale experimental tests, with wheel load placed at the distance *d* from the tip of the haunch to the edge of the load plate, were conducted on 24 typical precast concrete box culverts designated as per ASTM C1433-05. The test results further indicated that flexure governed the behaviour up to and beyond AASHTO 2005 factored load. Three-dimensional nonlinear finite-element models (FEMs) of the test specimens were developed and verified with the experimental results. The three-dimensional volumetric shear force distributions on the top slab of the 42 ASTM C1433-05 boxes were obtained by using the FEM from which the distribution width for each box was calculated. This was used to obtain the critical factored shear force for all the boxes which were then compared with the American Concrete Institute shear capacity equations. It was shown that the shear capacity exceeded the factored critical shear force for all the ASTM C1433-05 boxes. This study shows that the AASHTO 2005 provision with regard to the shear transfer device across the joint is unsupported.

2.9 Effect of Wheel Live Load on Shear Behaviour of Precast Reinforced Concrete Box Culverts by Anil K. Garg and Ali Abolmaali[8].

“This study reports on a part of a comprehensive study to evaluate the shear capacity of the precast reinforced concrete box culverts. Six full-scale 2.4 m (8 ft) span box culverts were tested to failure by subjecting each culvert to the AASHTO HS-20 wheel load. The location of the wheel load was varied from the tip of the haunch as a function of the top slab effective depth in order to identify the critical shear location. Each test specimen was loaded incrementally up to failure in which crack initiation and propagation were identified and recorded in each load step. In some specimens the top slab compression distribution steel was precluded during specimen fabrication the effect of which was shown to be insignificant in culvert’s performance experimentally. Even though the test specimens were loaded to introduce shear behaviour, it was shown that all the test specimens behaved in flexural mode up to and beyond standard factored live load. The test specimens only experienced shear cracks at loads equivalent to approximately twice of the aforementioned factored load. This study concludes that shear is not the governing behavioural mode for the concrete box culverts, and box culverts reported in the current standard need to be revisited.”

2.10 Experimental Investigation of Shear Capacity of Precast Reinforced Concrete Box Culverts by Anil K. Garg and Ali Abolmaali[9].

“This study presents an experimental program to investigate the shear capacity of precast reinforced concrete box culverts. Each culvert was subjected to monotonically increasing load through a 254 mm×508 mm (10 in.×20 in.) load plate in order to simulate the HS20 truckload per AASHTO 2005. Instrumentation included strain gauges, high-resolution laser deflection sensor, and automated data acquisition. Four tests were conducted on 1.22 m×1.22 m ×1.22 m (4 ft×4 ft×4 ft) box culverts. The location of the load plate was varied to identify the position, which introduces the maximum shear stresses. Laser sensor data and dial gauge readings were recorded to measure the deflection profile of the box culvert. Strain gauges were placed on the steel reinforcement to measure axial strain at locations of maximum positive and negative bending moments. The test results include reporting the loads at which each crack initiated and propagated. The displacement profile of the top slab from the laser instrumentation output along with the load versus maximum deflection for each culvert is also reported.”

2.11 Behaviour of Reinforced Concrete Box Culverts under High Embankments by Mario Pimentel, Pedro Costa, Carlos Félix and Joaquim Figueiras.[10]

“In this paper a numerical and an experimental study on reinforced concrete box culverts (BC) behaviour is presented. A BC under a 9.5 m high embankment was instrumented and observed during the construction period. Numerical analyses were then performed using a finite-element code capable of considering the construction sequence, the nonlinear behaviour of the reinforced concrete structure, and an elastic-plastic behaviour for the soil and the interfaces. Once the computed results were in good agreement with the observed behaviour, a parametric study was developed for the identification of the main parameters influencing the interaction mechanism and to evaluate the BC structural performance up to failure. The influence of the BC nonlinear behaviour on the interaction mechanism, both in service and ultimate limit state conditions, was analyzed and discussed. It is concluded that the soil pressures and the BC nonlinear behaviour are directly related and should be reflected in the design stage in order to achieve a more rational and economical design.”

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Chapter 3

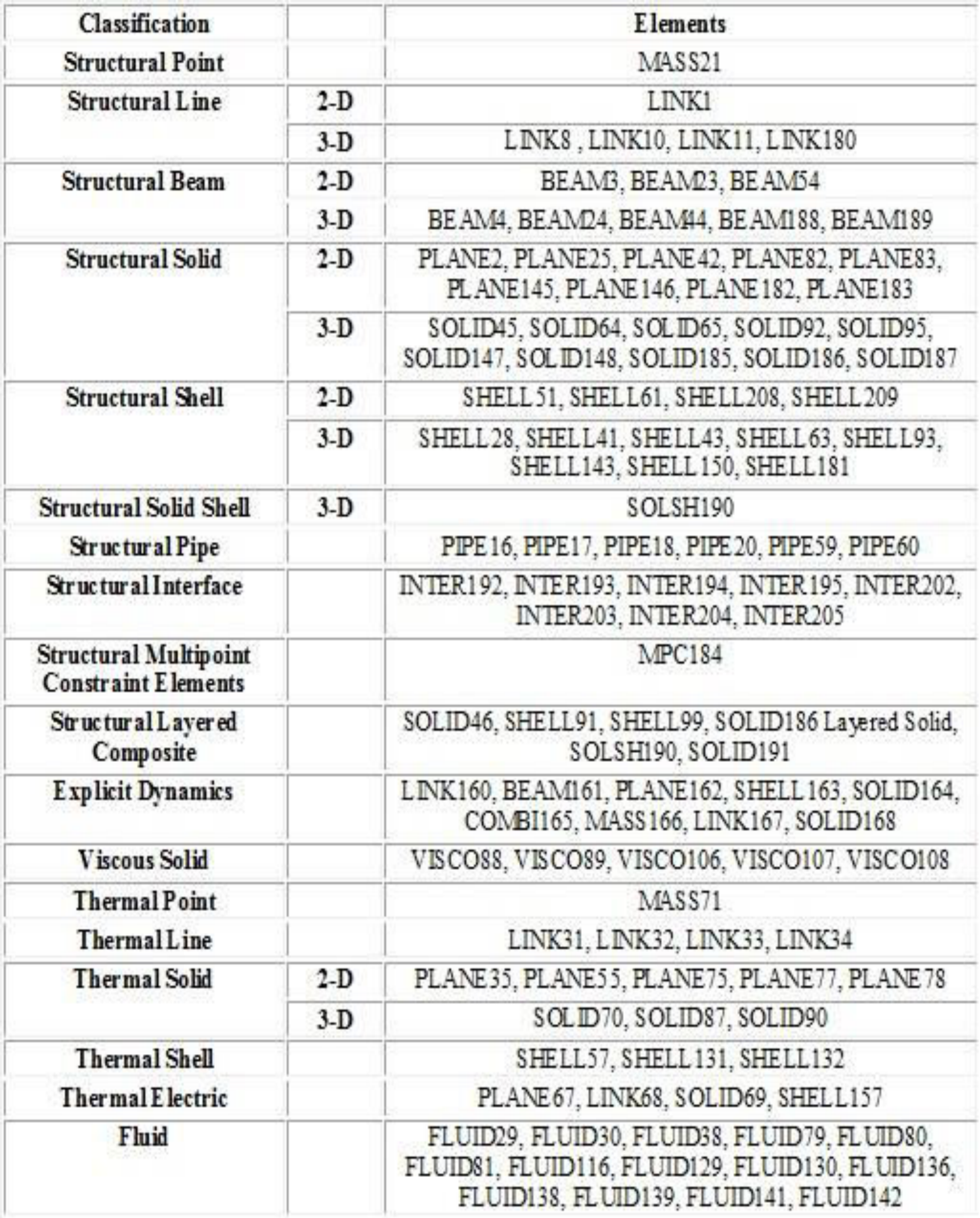
FEM Analysis in ANSYS

3.1 Introduction: Modeling is one of the most important and time taking operation in ANSYS. ANSYS allows modeling through three different modes mentioned below.

1) Interactive mode: This is the most common mode of interaction between user and the software. It includes activation of a platform known as Graphical User Interface (GUI), which is composed of menus, dialog boxes, push buttons, and different windows. Interactive mode is recommended mode for beginner ANSYS users as it provides an excellent platform for learning. It is also highly effective for post-processing.
2) Batch mode: This is mentioned to use the ANSYS program without activating the GUI. It involves an input file written in ANSYS Parametric Design Language (APDL), which allows the use of DO loops parameters and common programming features such as IF statements. These capabilities make the Batch Mode a very powerful analysis tool. Another distinct advantage of the Batch Mode is realized when there is an error in the generation of model. This problem can be fixed by modifying a small portion of the Input file and reading it again, saving the user a great deal of time.
3) Combined Mode: This is a combination of Interactive Mode and Batch Modes in which the user activates the GUI and reads the Input File. Typically, this method allows the user to generate their model and obtain respective solution using the input file while reviewing the results using the Postprocessor within the GUI. This method combines the salient advantages of Interactive and Batch Modes.

3.2 Classification of Finite elements in ANSYS: In ANSYS there are number of elements for different kinds of analysis they are classified as below:

Table 1: Finite Elements used in 'ANSYS'



Classification		Elements
Structural Point		MASS21
Structural Line	2-D	LINK1
	3-D	LINK8 , LINK10, LINK11, LINK180
Structural Beam	2-D	BEAM3, BEAM23, BEAM54
	3-D	BEAM4, BEAM24, BEAM44, BEAM188, BEAM189
Structural Solid	2-D	PLANE2, PLANE25, PLANE42, PLANE82, PLANE83, PLANE145, PLANE146, PLANE182, PLANE183
	3-D	SOLID45, SOLID64, SOLID65, SOLID92, SOLID95, SOLID147, SOLID148, SOLID185, SOLID186, SOLID187
Structural Shell	2-D	SHELL51, SHELL61, SHELL208, SHELL209
	3-D	SHELL28, SHELL41, SHELL43, SHELL63, SHELL93, SHELL143, SHELL150, SHELL181
Structural Solid Shell	3-D	SOLSH190
Structural Pipe		PIPE16, PIPE17, PIPE18, PIPE20, PIPE59, PIPE60
Structural Interface		INTER192, INTER193, INTER194, INTER195, INTER202, INTER203, INTER204, INTER205
Structural Multipoint Constraint Elements		MPC184
Structural Layered Composite		SOLID46, SHELL91, SHELL99, SOLID186 Layered Solid, SOLSH190, SOLID191
Explicit Dynamics		LINK160, BEAM161, PLANE162, SHELL163, SOLID164, COMBI165, MASS166, LINK167, SOLID168
Viscous Solid		VISCO88, VISCO89, VISCO106, VISCO107, VISCO108
Thermal Point		MASS71
Thermal Line		LINK31, LINK32, LINK33, LINK34
Thermal Solid	2-D	PLANE35, PLANE55, PLANE75, PLANE77, PLANE78
	3-D	SOLID70, SOLID87, SOLID90
Thermal Shell		SHELL57, SHELL131, SHELL132
Thermal Electric		PLANE67, LINK68, SOLID69, SHELL157
Fluid		FLUID29, FLUID30, FLUID38, FLUID79, FLUID80, FLUID81, FLUID116, FLUID129, FLUID130, FLUID136, FLUID138, FLUID139, FLUID141, FLUID142

Magnetic Electric		PLANE53, SOLID96, SOLID97, INTER115, SOLID117, HF118, HF119, HF120, PLANE121, SOLID122, SOLID123, SOLID127, SOLID128, PLANE230, SOLID231. SOLID232
Electric Circuit		SOURC36, CIRCU94, CIRCU124, CIRCU125
Electromechanical		TRANS109, TRANS126
Coupled-Field		SOLID5, PLANE13, SOLID62, SOLID98, ROM144, PLANE223, SOLID226, SOLID227
Contact		CONTAC12, CONTAC52, TARGE169, TARGE170, CONTA171, CONTA172, CONTA173, CONTA174, CONTA175, CONTA176, CONTA178
Combination		COMBIN7, COMBIN14, COMBIN37, COMBIN39, COMBIN40, PRETS179
Matrix		MATRIX27, MATRIX50
Infinite		INFIN9, INFIN47, INFIN110, INFIN111
Surface		SURF151, SURF152, SURF153, SURF154, SURF156, SURF251, SURF252
Follower Load		FOLLW201
Meshing		MESH200

3.2.1 SOLID65 Element Description: SOLID65 is used for accurate 3-D modeling of structure with or without reinforcing bars. The structure is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiber glass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined.

The concrete element is similar to the SOLID45 (3-D Structural Solid) element with the addition of special cracking and crushing capabilities. The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep.

3.2.2 SOLID65 as a Concrete Material Model: The SOLID65 element was used to model the concrete. This lament has eight nodes with three degrees of freedom at each node – translations in the nodal X, Y, and Z directions. The element is capable of plastic deformation, cracking in three mutually perpendicular directions and crushing. SOLID65 element decides the cracking and crushing of concrete through this material model. A material model maybe composed of two or more material definitions. Concrete material should have at least Elastic and Concrete material definition. In elastic definition, the modulus of elasticity and poison’s ratio are necessary. The modulus of elasticity of concrete can be determined by either experiments or existing formulations. For concrete definitions, axial tension strength of concrete and shear transfer coefficients between crack surfaces for open and closed cracks are required. If the shear transfer from one crack surface to other does not exist then the shear coefficient is 0.0, if it fully exists then the coefficient is 1.0. In the literature, there are different suggestions for this coefficient by researchers.

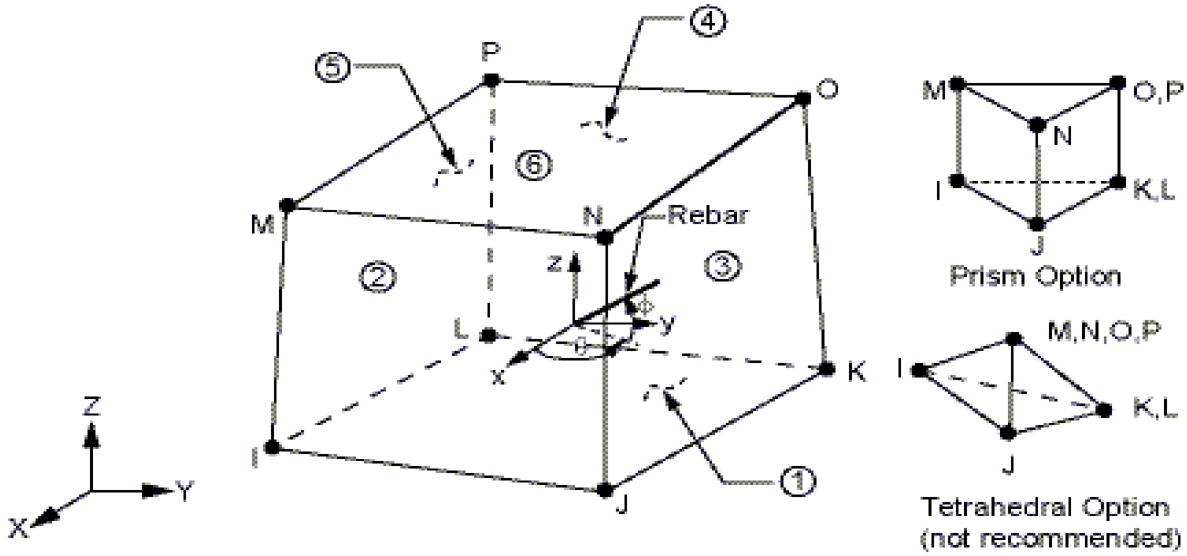


Fig. 3.1 SOLID65 Element

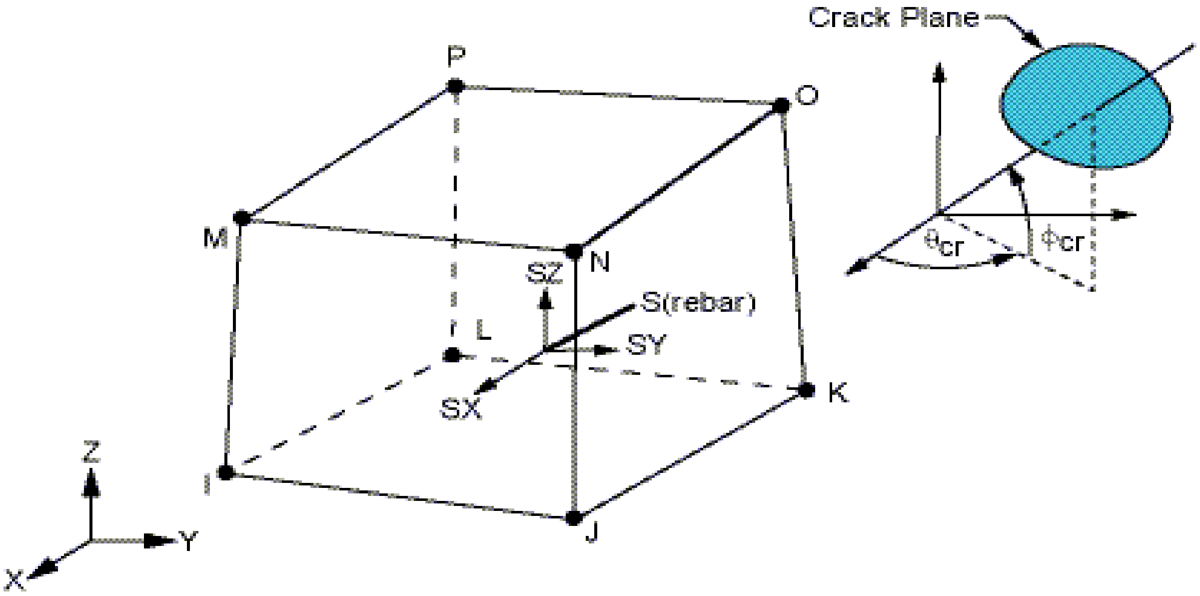


Fig. 3.2 SOLID45 Element

3.2.3 Few typical elements used in FEM

- *Constant strain triangle (CST or T3)*
- *Linear strain triangle (LST or T6)*
- *Linear quadrilateral element (Q4)*
- *Quadratic quadrilateral element (Q8)*

The diagrams of the above elements are shown in the following with their degree of freedoms and shapes in the finite element method.

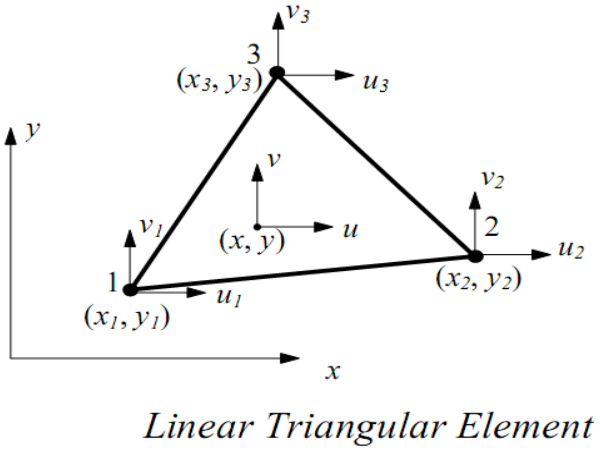


Fig. 3.3 Constant strain triangle

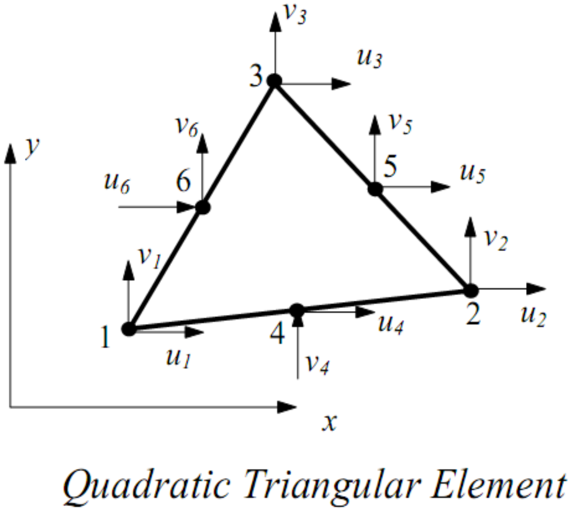


Fig. 3.4 Linear strain triangle

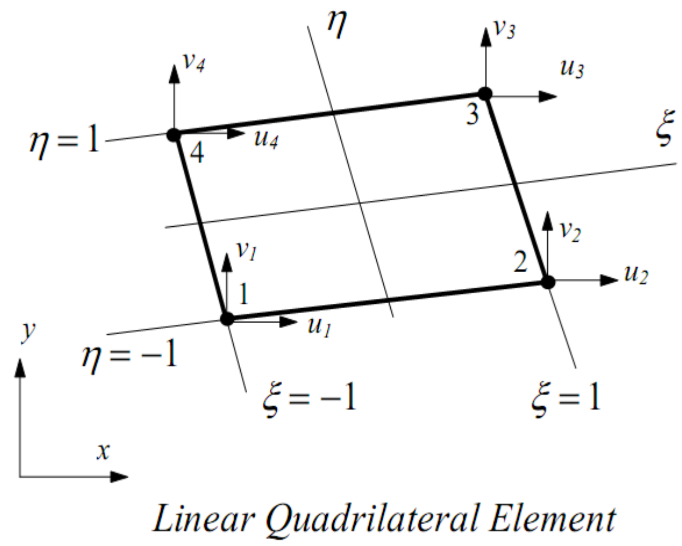


Fig. 3.5 Linear quadrilateral element

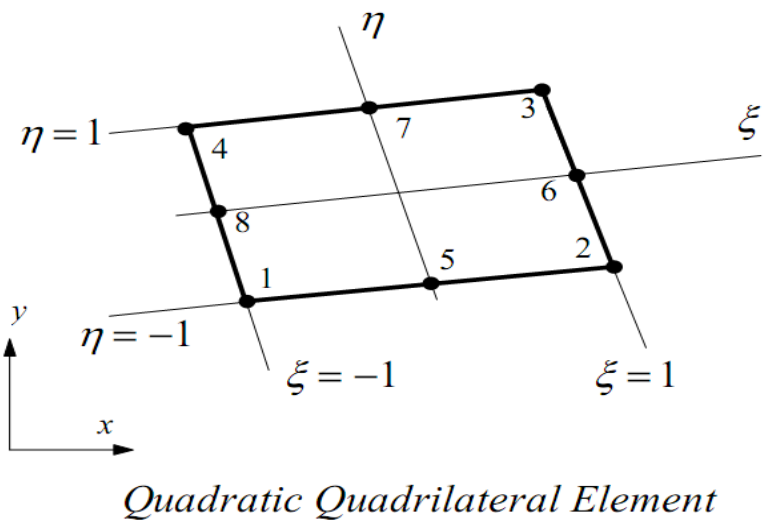


Fig. 3.6 Quadratic quadrilateral element

3.3 Input data for Elastic material definition:

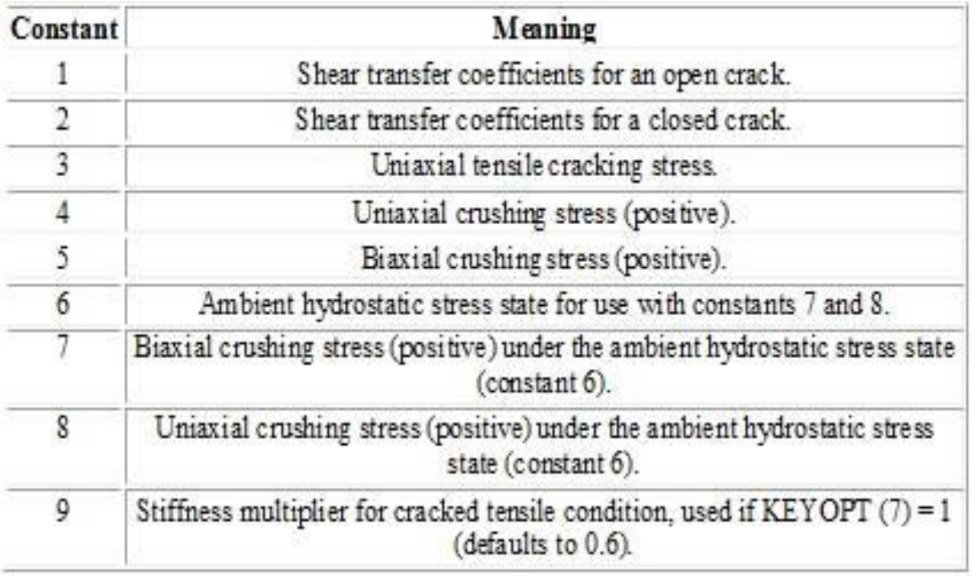
Following are the input parameters required for Elastic Material definition.

1) Modulus of Elasticity
2) Poisons ratio

3.3.1 Input parameters for Concrete material definition:

Following are the input parameters required for Elastic Material definition.

Table 2: Input parameters for Concrete material definition



Constant	Meaning
1	Shear transfer coefficients for an open crack.
2	Shear transfer coefficients for a closed crack.
3	Uniaxial tensile cracking stress.
4	Uniaxial crushing stress (positive).
5	Biaxial crushing stress (positive).
6	Ambient hydrostatic stress state for use with constants 7 and 8.
7	Biaxial crushing stress (positive) under the ambient hydrostatic stress state (constant 6).
8	Uniaxial crushing stress (positive) under the ambient hydrostatic stress state (constant 6).
9	Stiffness multiplier for cracked tensile condition, used if KEYOPT (7) = 1 (defaults to 0.6).

In the present modeling only Elastic material data has entered as this work is concerned about stress results and not for crack and crushing results.

For present modeling concrete of M20 grade is used.

For M20 grade concrete, modulus of elasticity = $5000\sqrt{f}_{ck}$ = 2.2360×10^4 N/mm^2

Poisons ratio = 0.17

3.3.2 Real Constants: SOLID65 element requires another additional parameter called as Real Constants. Real Constants for SOLID65 includes volume ratio i.e. ratio of area of steel to area of concrete i.e. φ, θ etc. As in this, analysis is done only on plane concrete to get actual stress results, parameters φ and θ have set to zero.

Table 3: Real constants for 'SOLID65' element

Real Constant No.	Rebar 1				Rebar 2				Rebar 2			
	Material No.	Volume Ratio	θ	φ	Material No.	Volume Ratio	θ	φ	Material No.	Volume Ratio	Θ	φ
1	0	0	0	0	0	0	0	0	0	0	0	0

3.4 Meshing: In the present modeling rectangular meshing is used. Rectangular meshing gives better results than the tetrahedral meshing. Edge length for meshing preferred is 0.1 m i.e. each finite element after meshing will be a cube of length 0.1m.

Following is the figure showing size of finite element after meshing.

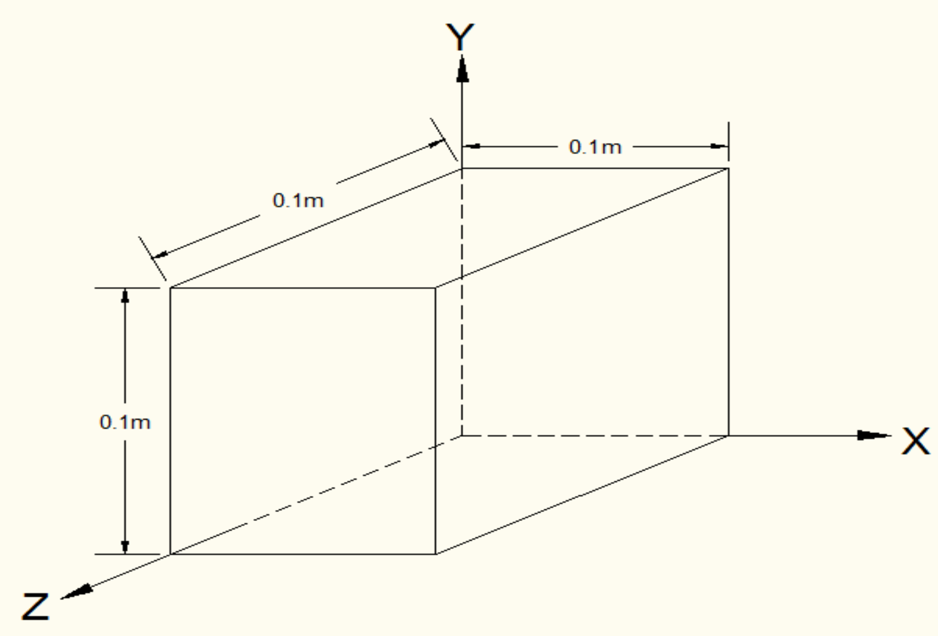


Fig. 3.7 Size and Shape of finite element

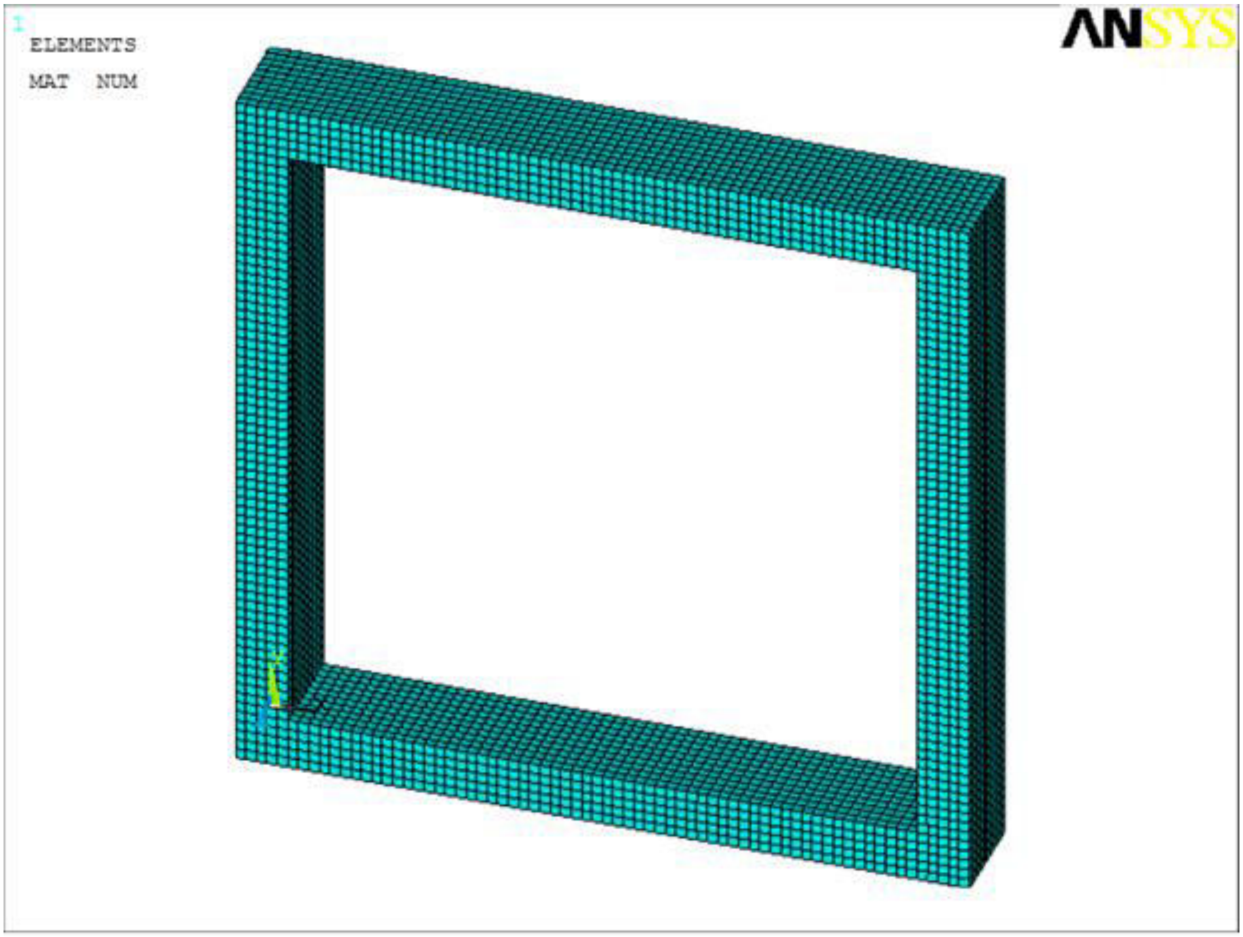


Fig. 3.8 Meshed Box Culvert Model without haunch

Chapter 4

Results from Post-processing mode

4.1 General:

After analysis results will be obtained from post-processing mode. In ANSYS results can be obtained in two ways,

1) Nodal solutions: In Nodal solution mode we can get results for stresses and deflection at each and every node.
2) Elemental solutions: In Elemental solution mode we can get results for stresses and deflection at each and every finite element.

Following type of results obtained from post-processing,

1) Results for Stresses
    a. X-Direction stresses
    b. Y-Direction stresses
    c. 3D-Principle stresses
    d. XY- Shear stresses
    e. Stress intensity
2) Results for deflection
    a. UY i.e deflection in global Y direction
3) Graphical solution:
    a. X- Direction stresses along top fiber.
    b. X- Direction stresses along bottom fiber.
    c. XY- Shear stresses along top fiber.
    d. XY- Shear stresses along bottom fiber.
    e. 3D-Principle stresses along top fiber.
    f. 3D-Principle stresses along bottom fiber.
    g. Y- Direction deflection along top fiber.
    h. Y- Direction deflection along bottom fiber.

4.2 Loading: In present analysis FEM analysis of box culvert has been done for a general load condition of surface load having magnitude of 60 kN/m^2 on all four outer sides acting inward.

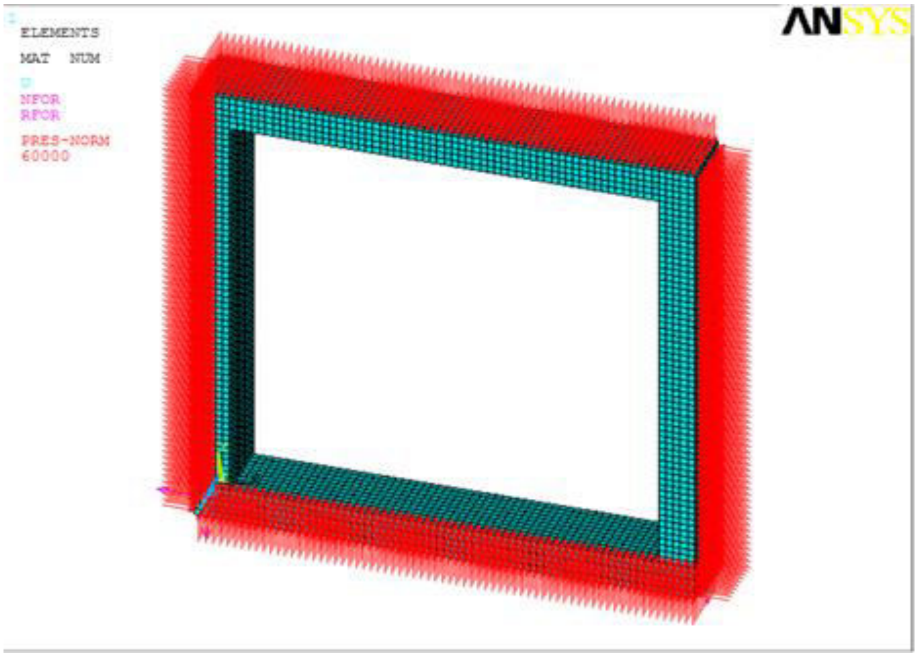


Fig. 4.1 Loading on Box Culvert

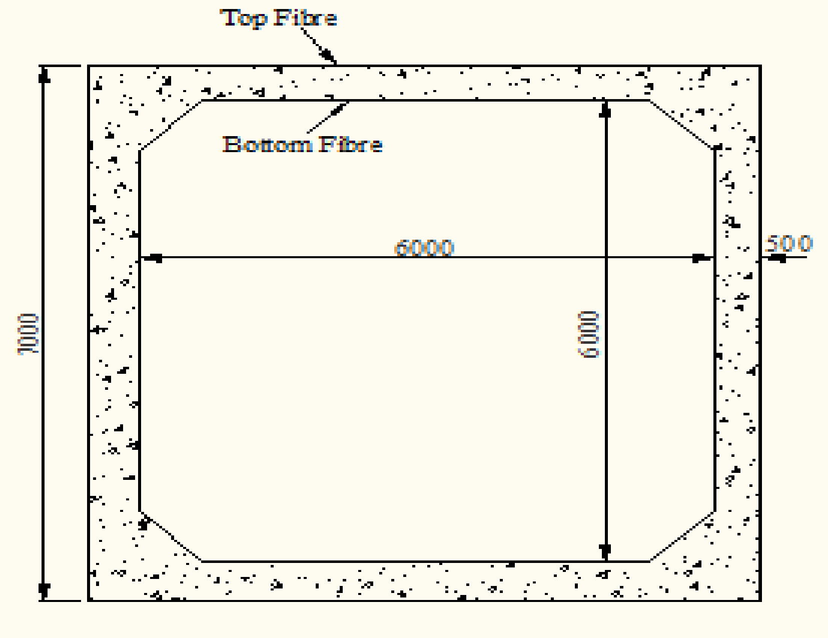


Fig. 4.2 Box Culvert model

4.3 X-Direction stresses:

4.3.1 X-Direction stresses for Box Culvert without haunch:

Table 4: X-Direction stresses for Box Culvert without haunch

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	3.10
Maximum compressive stress	6.89

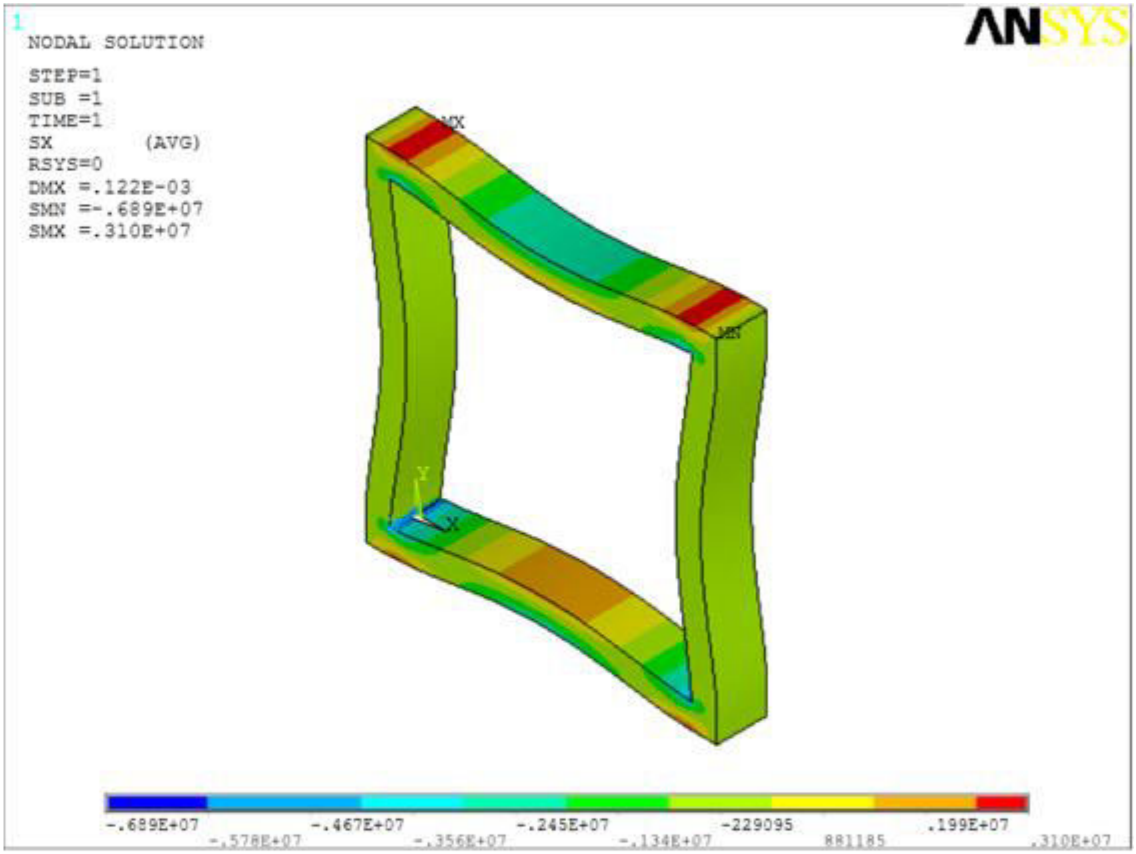


Fig. 4.3 X-direction stresses for no haunch model

Maximum tensile stress occurs at a distance of X=0.5m as shown in which the location where top horizontal slab and side vertical wall meets.

Maximum compressive stress occurs at a distance at the corner.

4.3.2 X-Direction stresses for Box Culvert with haunch size 0.5T:

Table 5: X-Direction stresses for Box Culvert with haunch size 0.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	2.46
Maximum compressive stress	4.91

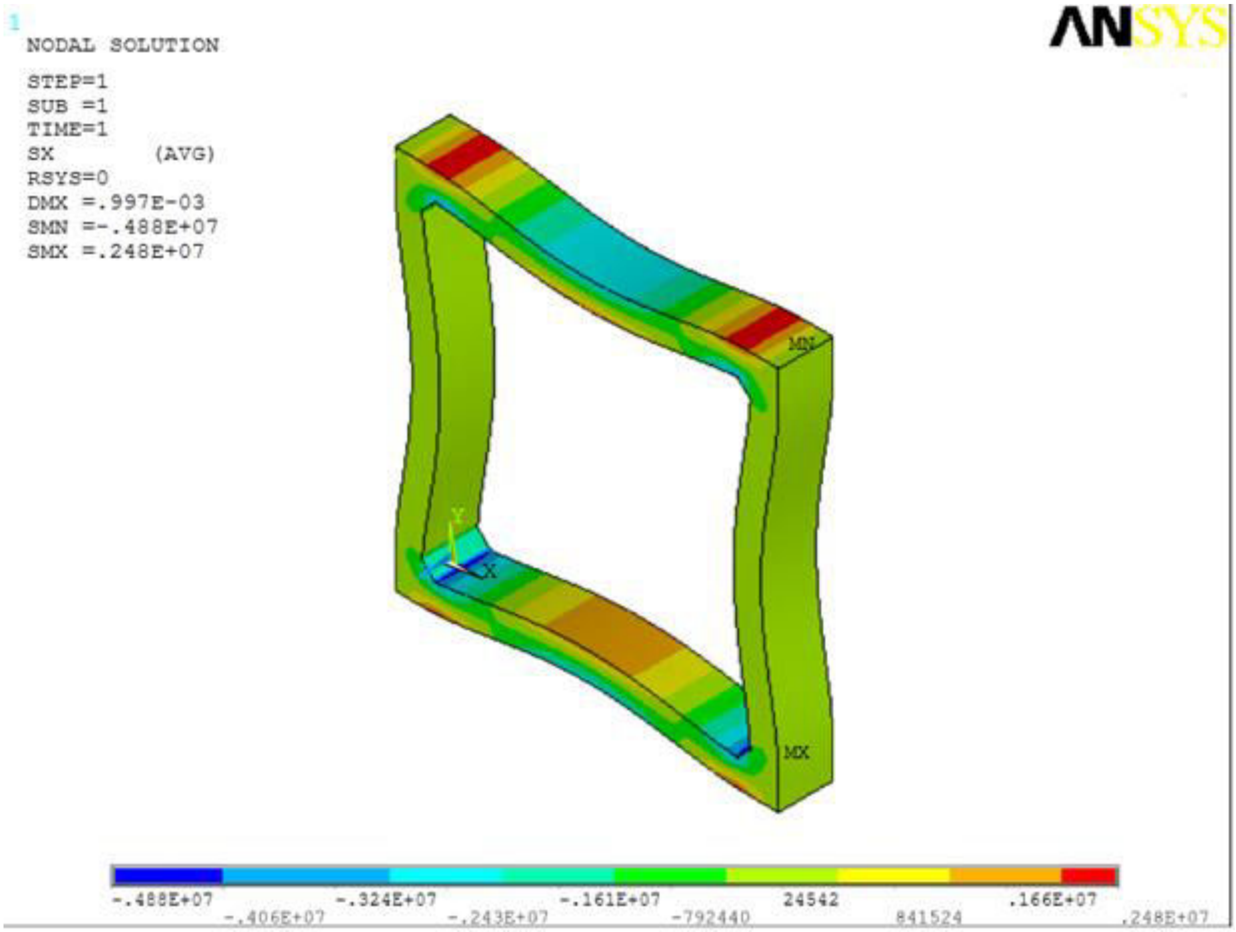


Fig. 4.4 X-direction stresses for haunch size 0.5T

Maximum tensile stress occurs at a distance of X=0.725m as shown in which is the location where top horizontal slab and side vertical wall meets.

Maximum compressive stress occurs at a distance at the corner just near the end of haunch.

4.3.3 X-Direction stresses for Box Culvert with haunch size 1T:

Table 6: X-Direction stresses for Box Culvert with haunch size 1T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.88
Maximum compressive stress	4.11

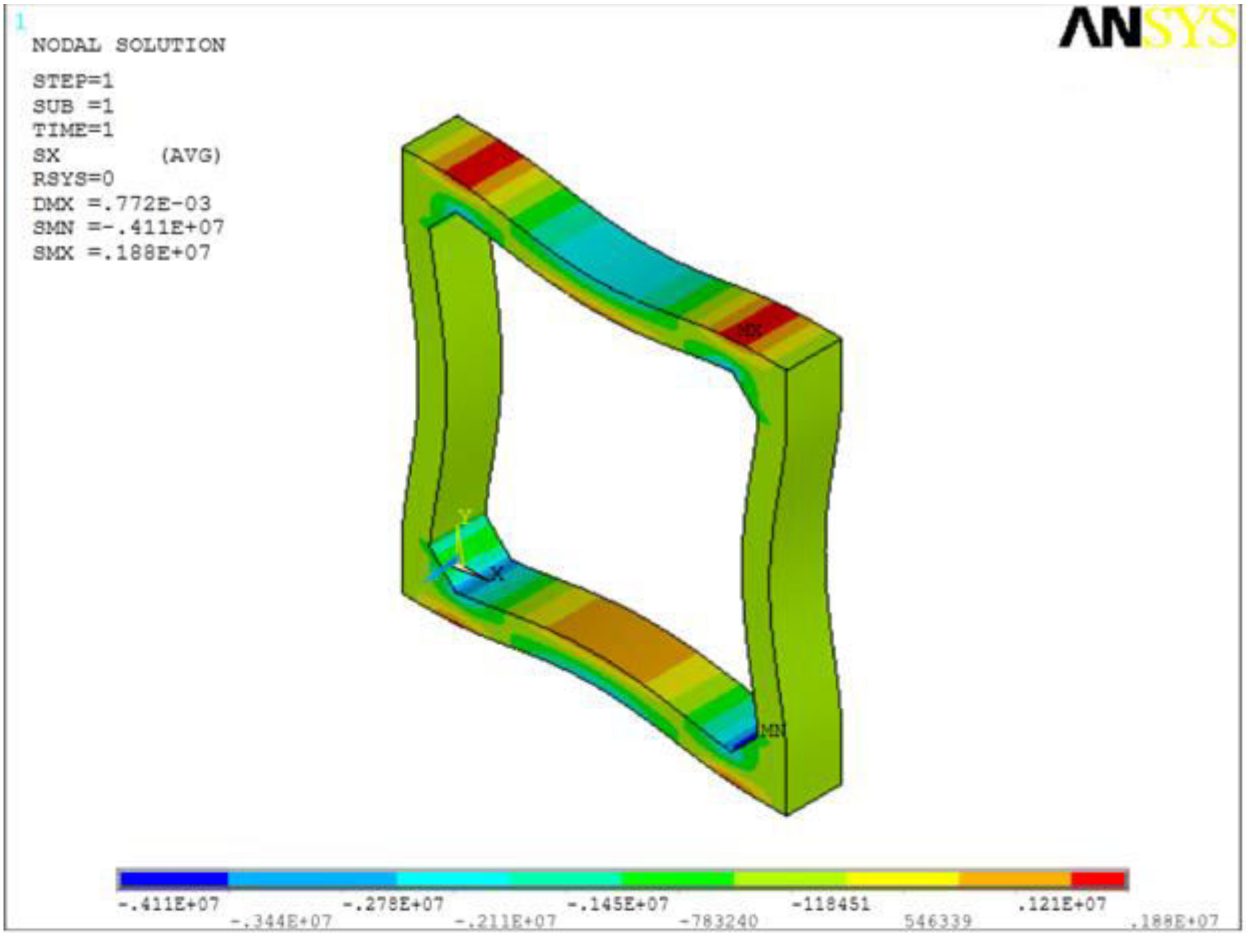


Fig. 4.5 X-direction stresses for haunch size 1.0T

Maximum tensile stress occurs at a distance of X=1m as shown in which is the location where top horizontal slab and side vertical wall meets.

Maximum compressive stress occurs at a distance at the corner just near the end of haunch.

4.3.4 X-Direction stresses for Box Culvert with haunch size 1.5T:

Table 7: X-Direction stresses for Box Culvert with haunch size 1.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.38
Maximum compressive stress	3.31

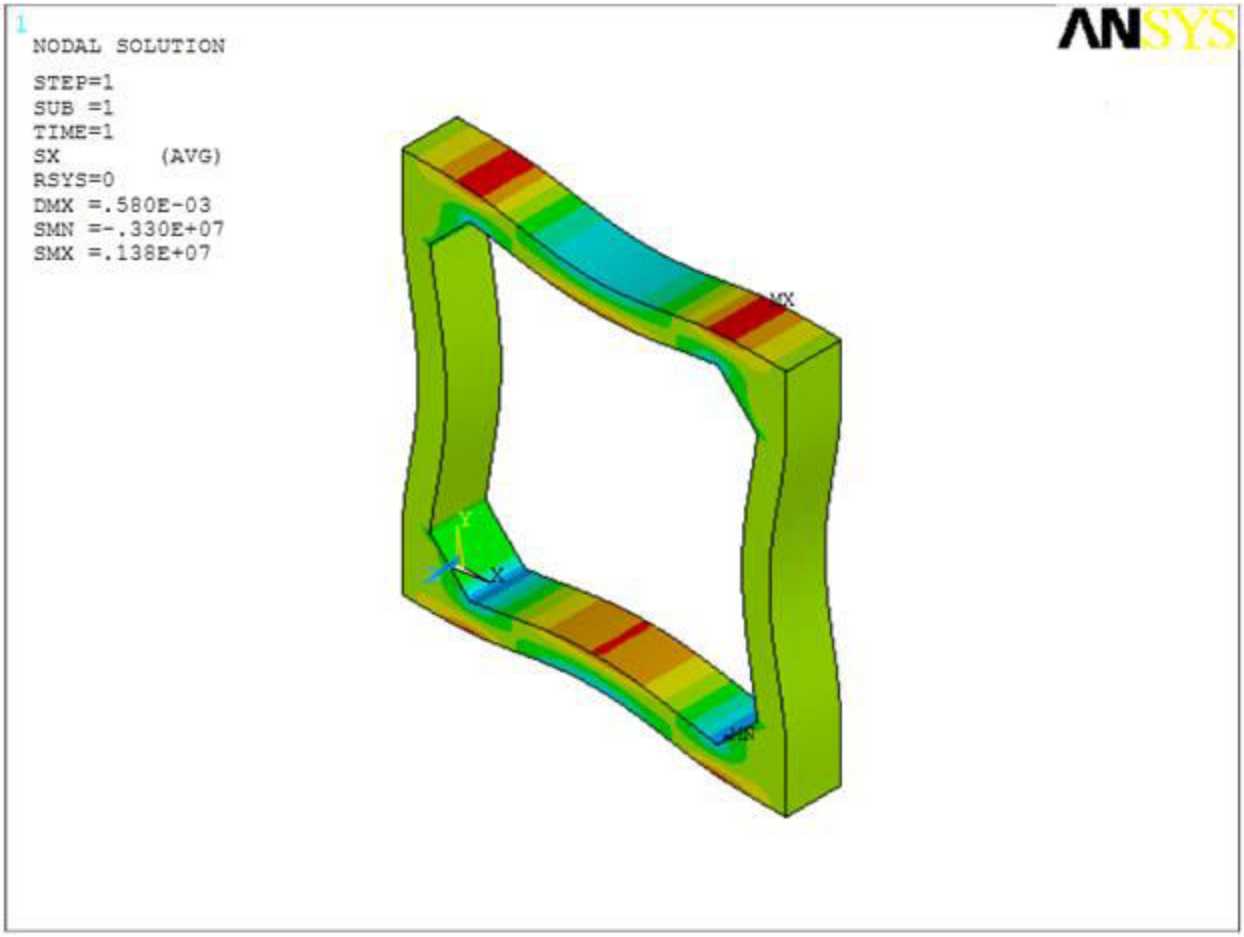


Fig. 4.6 X-direction stresses for haunch size 1.5T

Maximum tensile stress occurs at a distance of X=1.250m as shown in which is the location where top horizontal slab and side vertical wall meets.

Maximum compressive stress occurs at a distance at the corner just near the end of haunch.

4.3.5 X-Direction stresses for Box Culvert with haunch size 2T:

Table 8: X-Direction stresses for Box Culvert with haunch size 2T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	0.9523
Maximum compressive stress	2.72

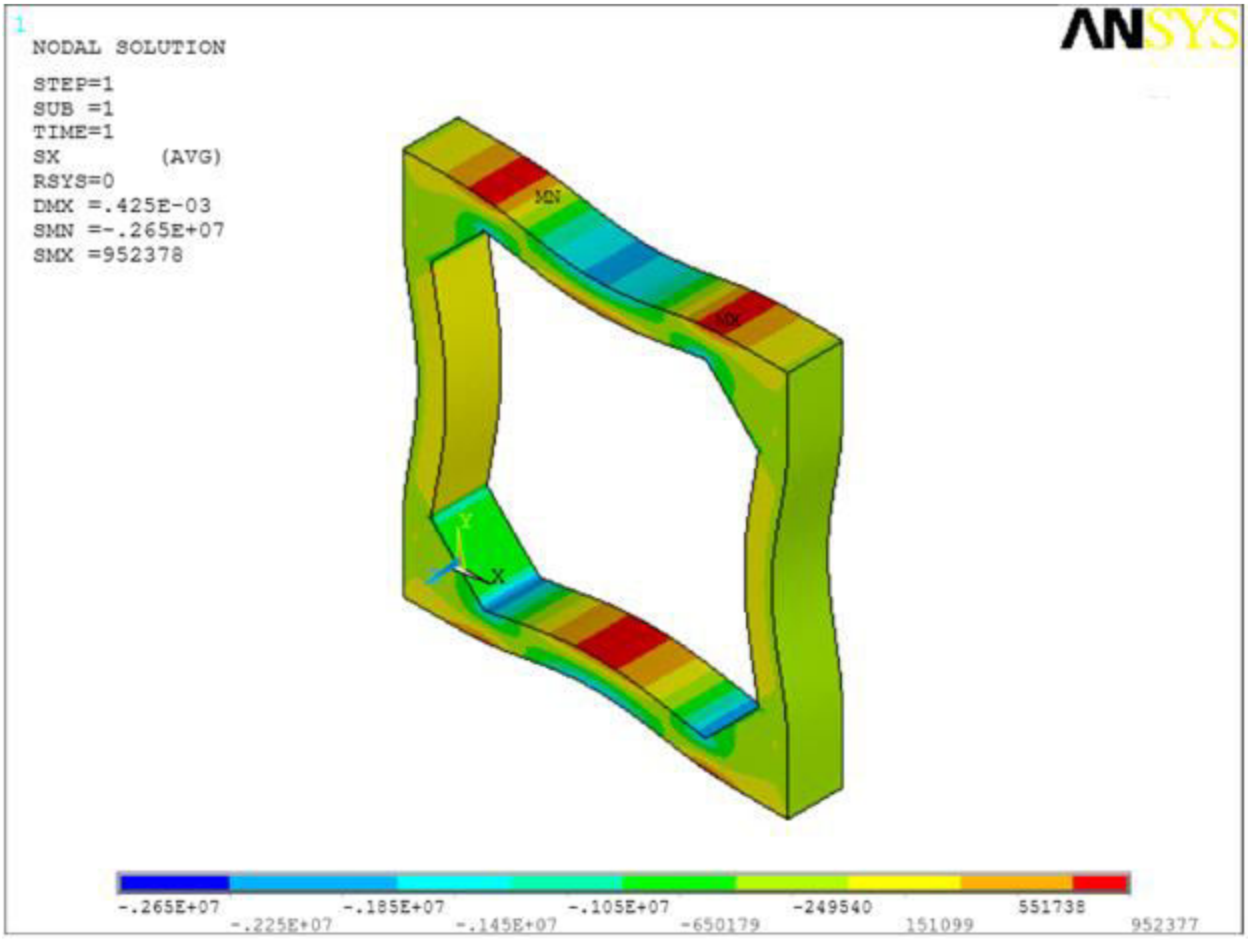


Fig. 4.7 X-direction stresses for haunch size 2T

Maximum tensile stress occurs at a distance of X=1.50m as shown in which the location is where top horizontal slab and side vertical wall meets.

Maximum compressive stress occurs at a distance at the corner just near the end of haunch.

4.4 X-Direction stresses on graph:

X-Direction stresses have been plotted on graph along following path

1) Along top slab top fiber
2) Along top slab bottom fiber
3) Along depth at a distance X = 3.5m
4) Along depth at the end of haunch

Following is the path shown in figure along which X-Direction stresses have been plotted.

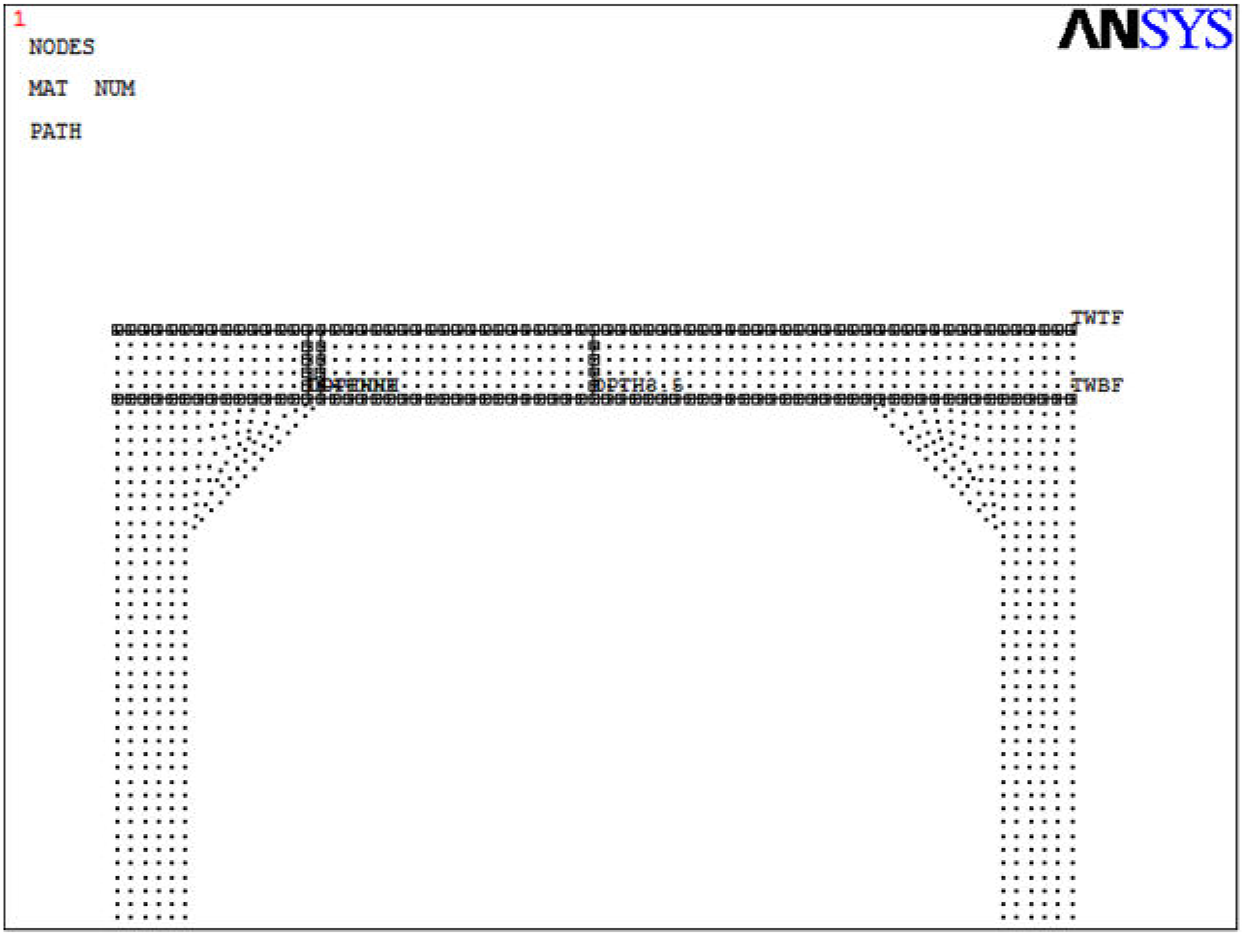


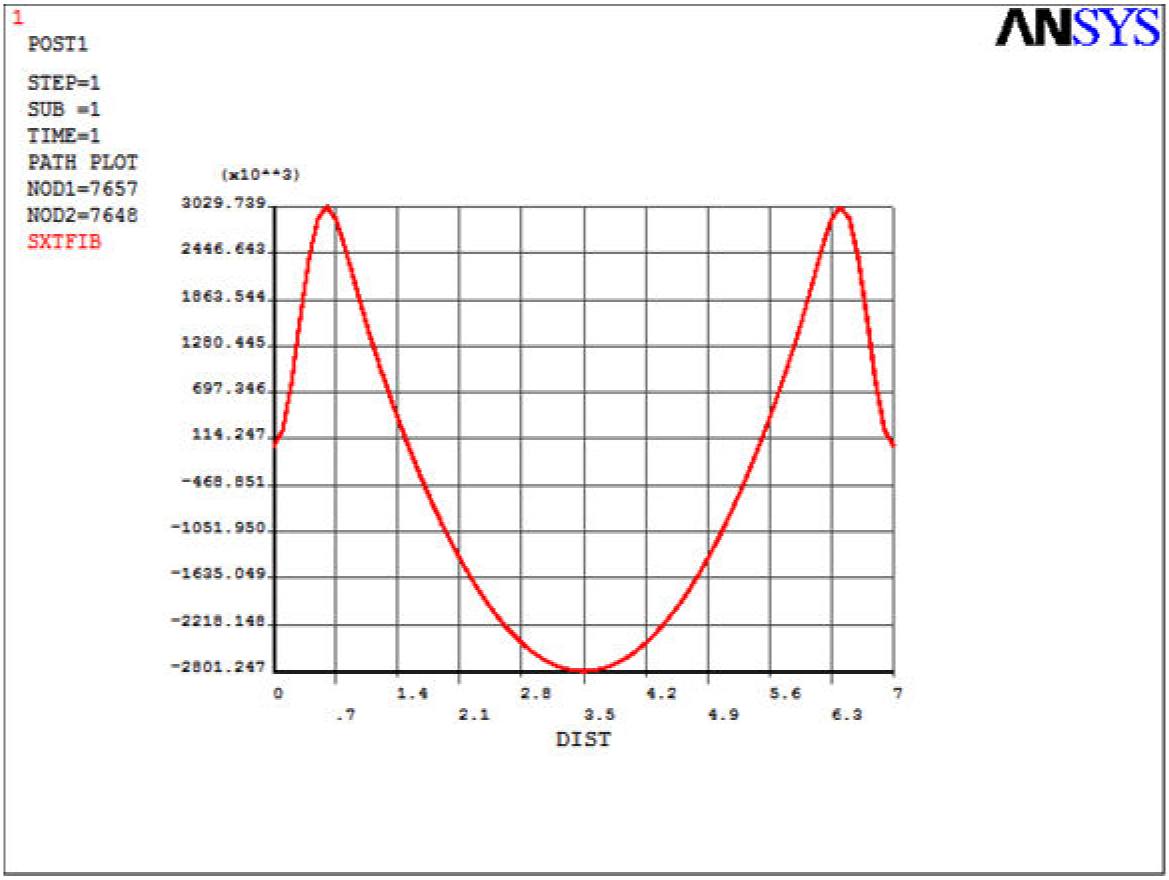
Fig. 4.8 Paths selected for plotting of X-direction stresses

4.4.1 X-Direction stresses on graph along top slab top fiber:

4.4.1.1 Box Culvert without haunch:

Table 9: X-Direction stresses for Box Culvert with no haunch

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	3.029
Maximum compressive stress	2.801



Graph 4.1 X-direction stresses along top fiber for no haunch model

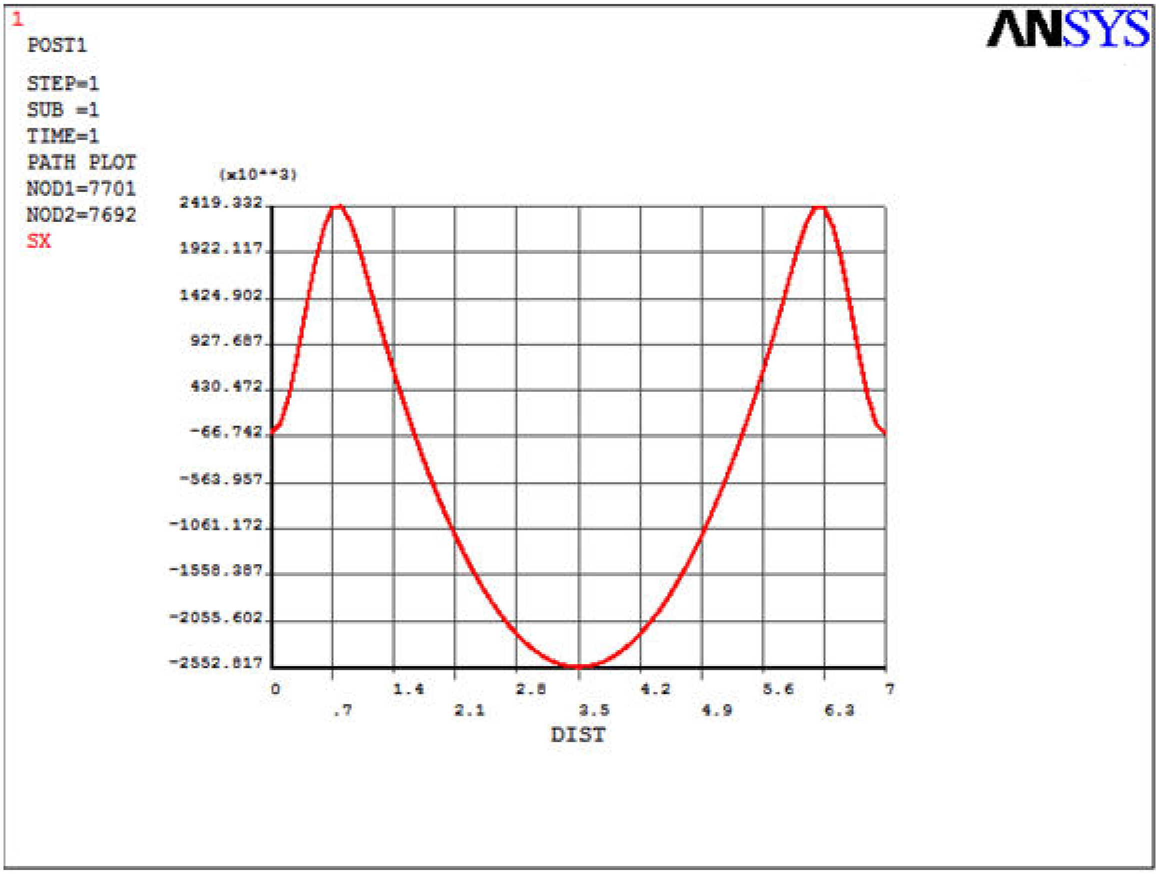
Maximum tensile stress occurs at a distance of X=0.5m as shown in graph which is the location where top horizontal slab and side vertical wall meets.

Maximum compressive stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.1.2 Box Culvert with haunch size 0.5T:

Table 10: X-Direction stresses for Box Culvert with haunch size 0.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	2.419
Maximum compressive stress	2.552



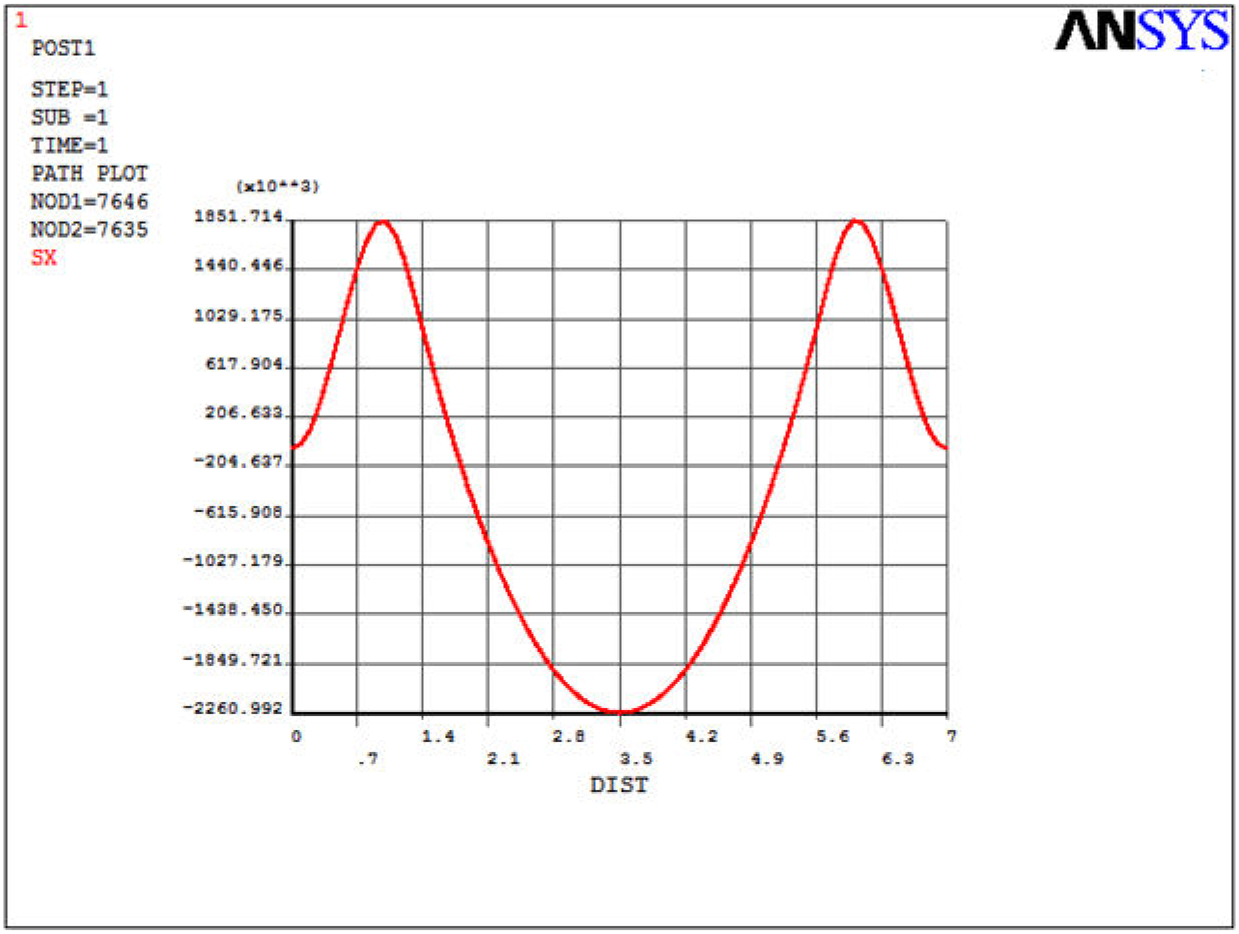
Graph 4.2 X-direction stresses along top fiber for haunch size 0.5T

Maximum tensile stress occurs at a distance of X=0.725m as shown in graph which is the location where haunch ends. Maximum compressive stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.1.3 Box Culvert with haunch size 1T:

Table 11: X-Direction stresses for Box Culvert with haunch size 1T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.851
Maximum compressive stress	2.260



Graph 4.3 X-direction stresses along top fiber for haunch size 1.0T

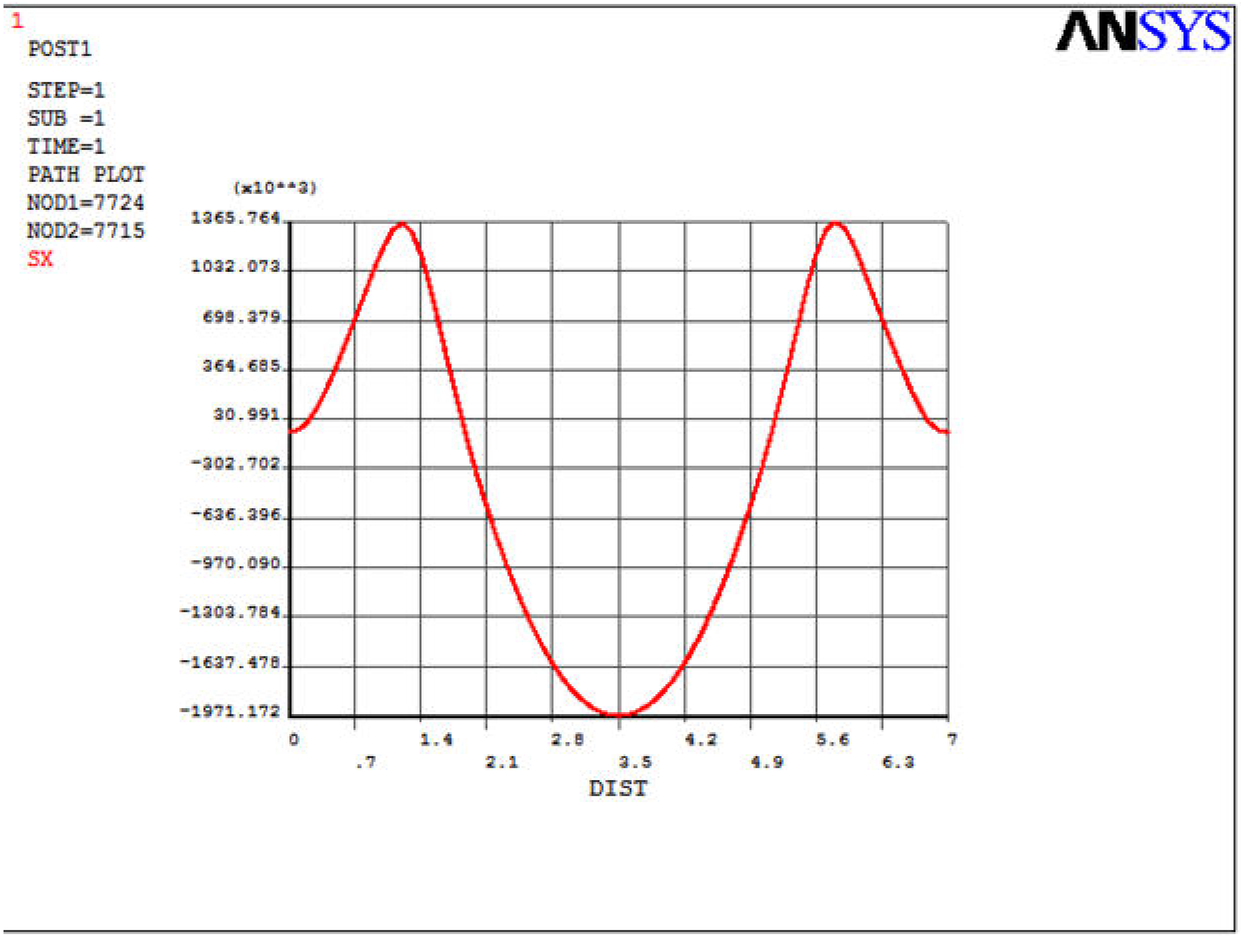
Maximum tensile stress occurs at a distance of X=1m as shown in graph which is the location where haunch ends.

Maximum compressive stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.1.4 Box Culvert with haunch size 1.5T:

Table 12: X-Direction stresses for Box Culvert with haunch size 1.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.365
Maximum compressive stress	1.971



Graph 4.4 X-direction stresses along top fiber for haunch size 1.5T

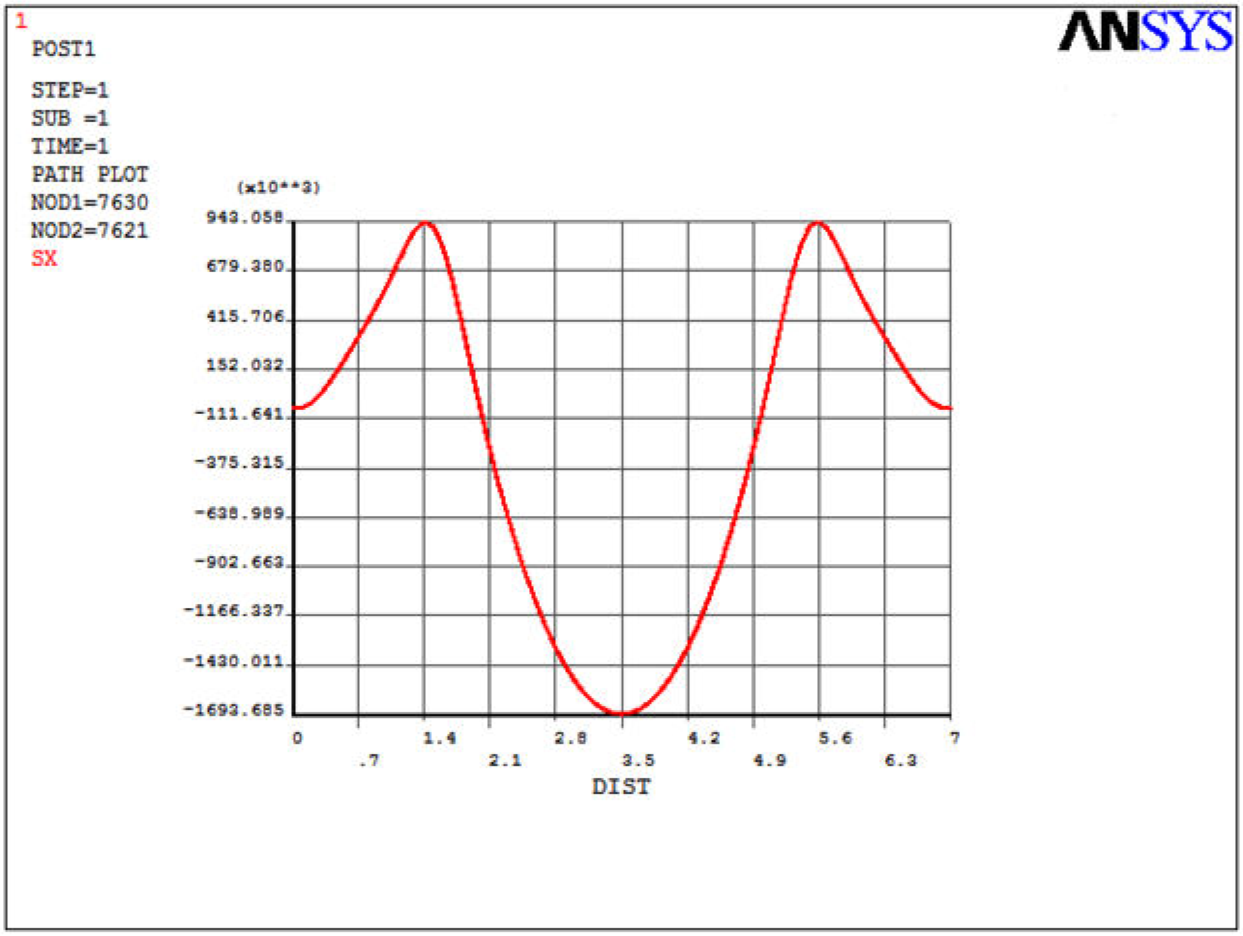
Maximum tensile stress occurs at a distance of X=1.250m as shown in graph which is the location where haunch ends.

Maximum compressive stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.1.5 Box Culvert with haunch size 2T:

Table 13: X-Direction stresses for Box Culvert with haunch size 2T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	0.943
Maximum compressive stress	1.693



Graph 4.5 X-direction stresses along top fiber for haunch size 2.0T

Maximum tensile stress occurs at a distance of X=1.45m as shown in graph which is the location where haunch ends.

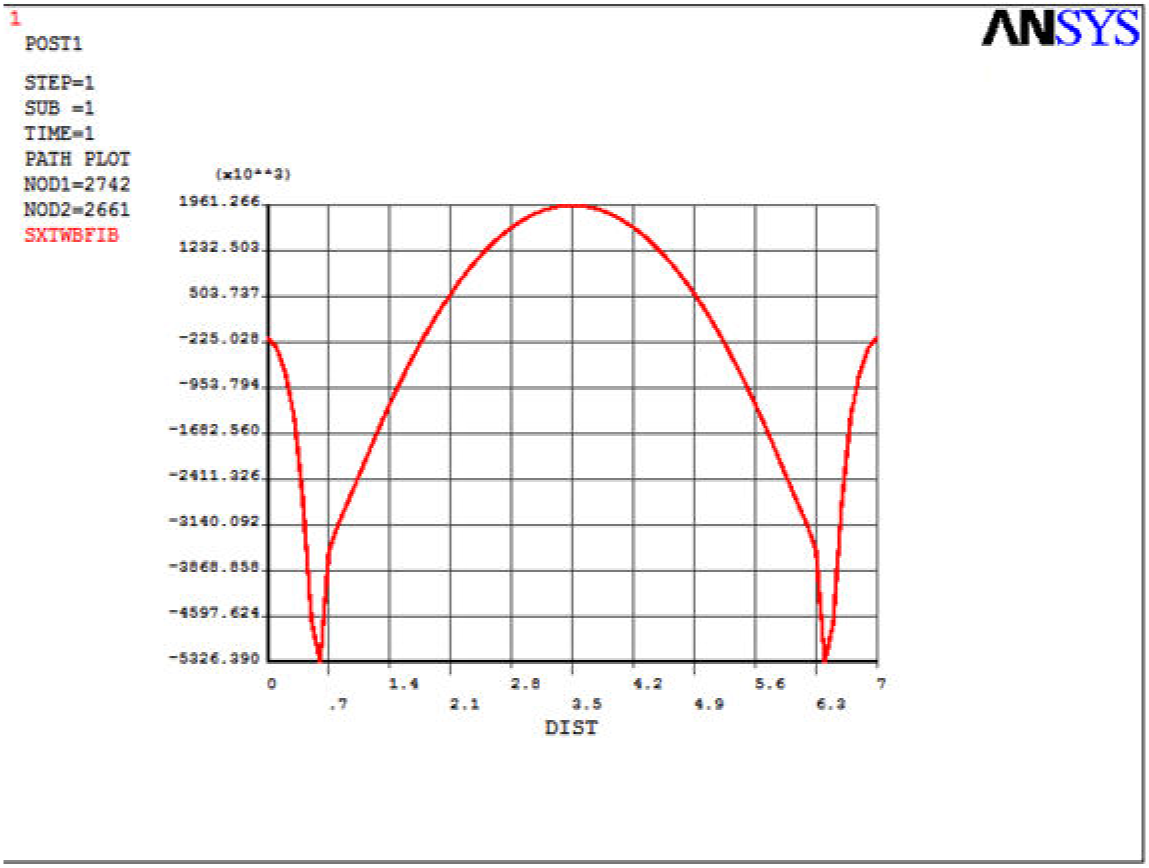
Maximum compressive stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.2 X-Direction stresses on graph along top slab bottom fiber:

4.4.2.1 Box Culvert without haunch:

Table 14: X-Direction stresses for Box Culvert with no haunch

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.961
Maximum compressive stress	5.326



Graph 4.6 X-direction stresses along bottom fiber for no haunch

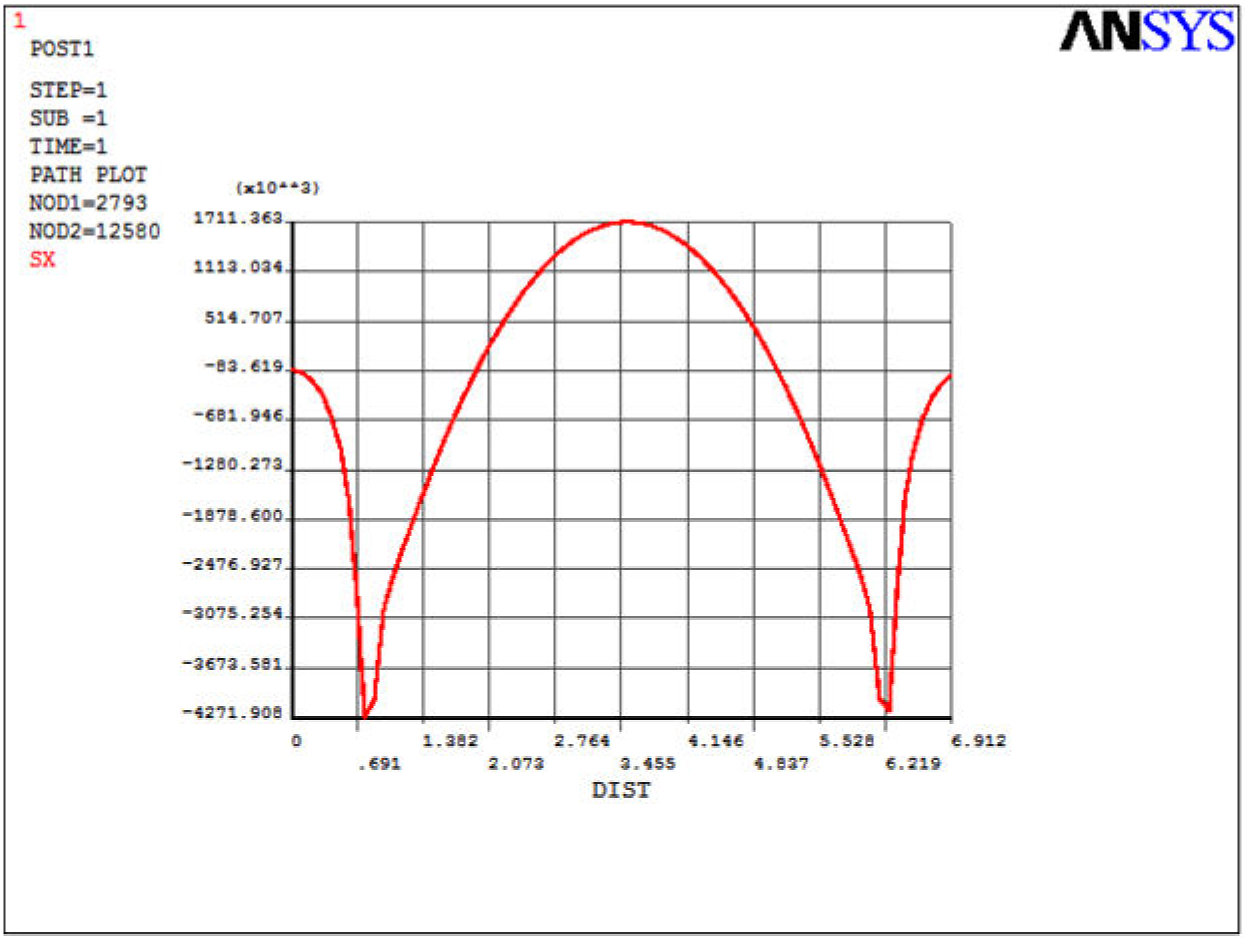
Maximum compressive stress occurs at a distance of X=0.5m as shown in graph which is the corner where top horizontal slab and side vertical wall meets.

Maximum tensile stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.2.2 Box Culvert with haunch size 0.5T:

Table 15: X-Direction stresses for Box Culvert with haunch size 0.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.711
Maximum compressive stress	4.271



Graph 4.7 X-direction stresses along bottom fiber for haunch size 0.5T

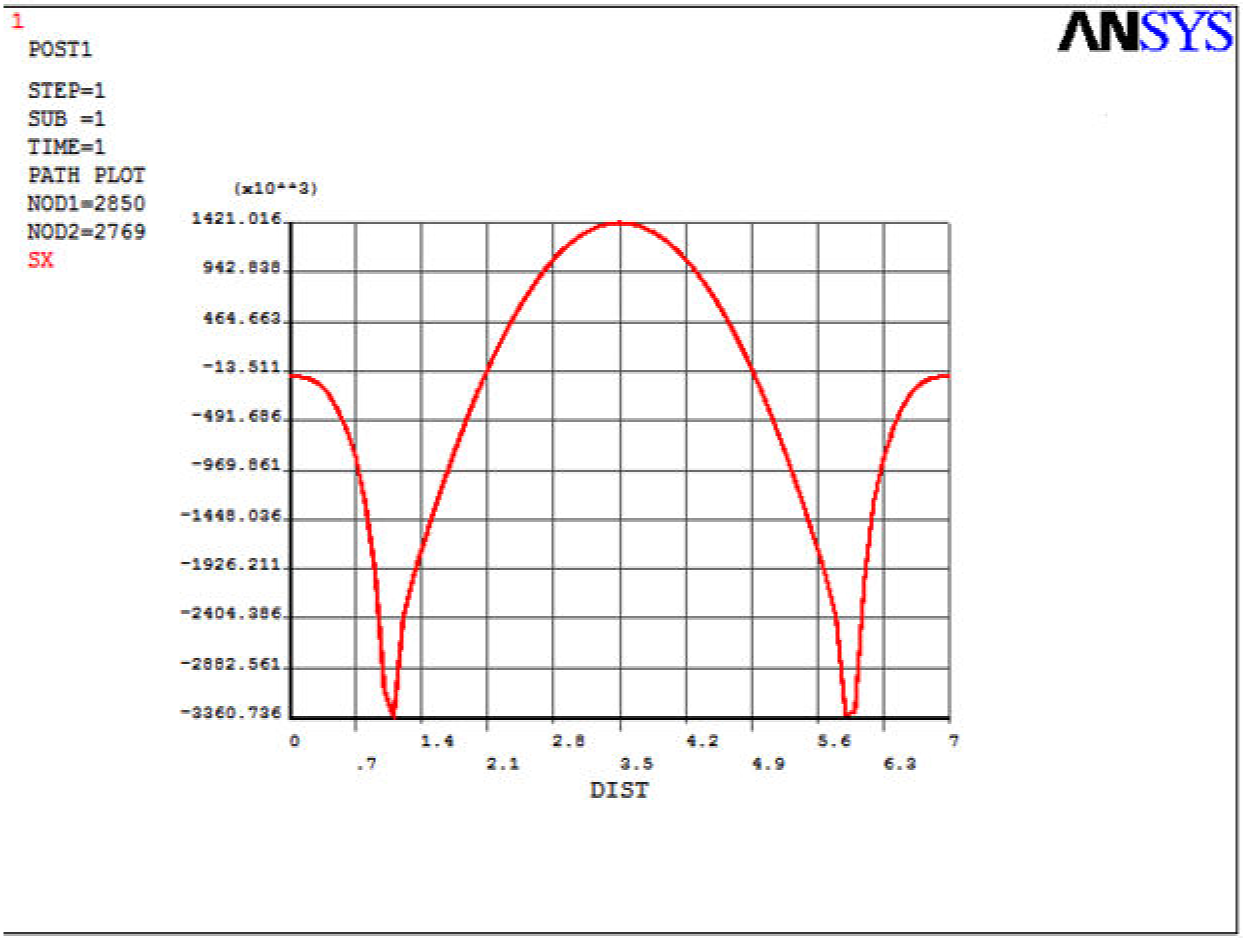
Maximum compressive stress occurs at a distance of X=0.725m as shown in graph which is the location where haunch ends.

Maximum tensile stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.2.3 Box Culvert with haunch size 1T:

Table 16: X-Direction stresses for Box Culvert with haunch size 1T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.421
Maximum compressive stress	3.360



Graph 4.8 X-direction stresses along bottom fiber for haunch size 1.0T

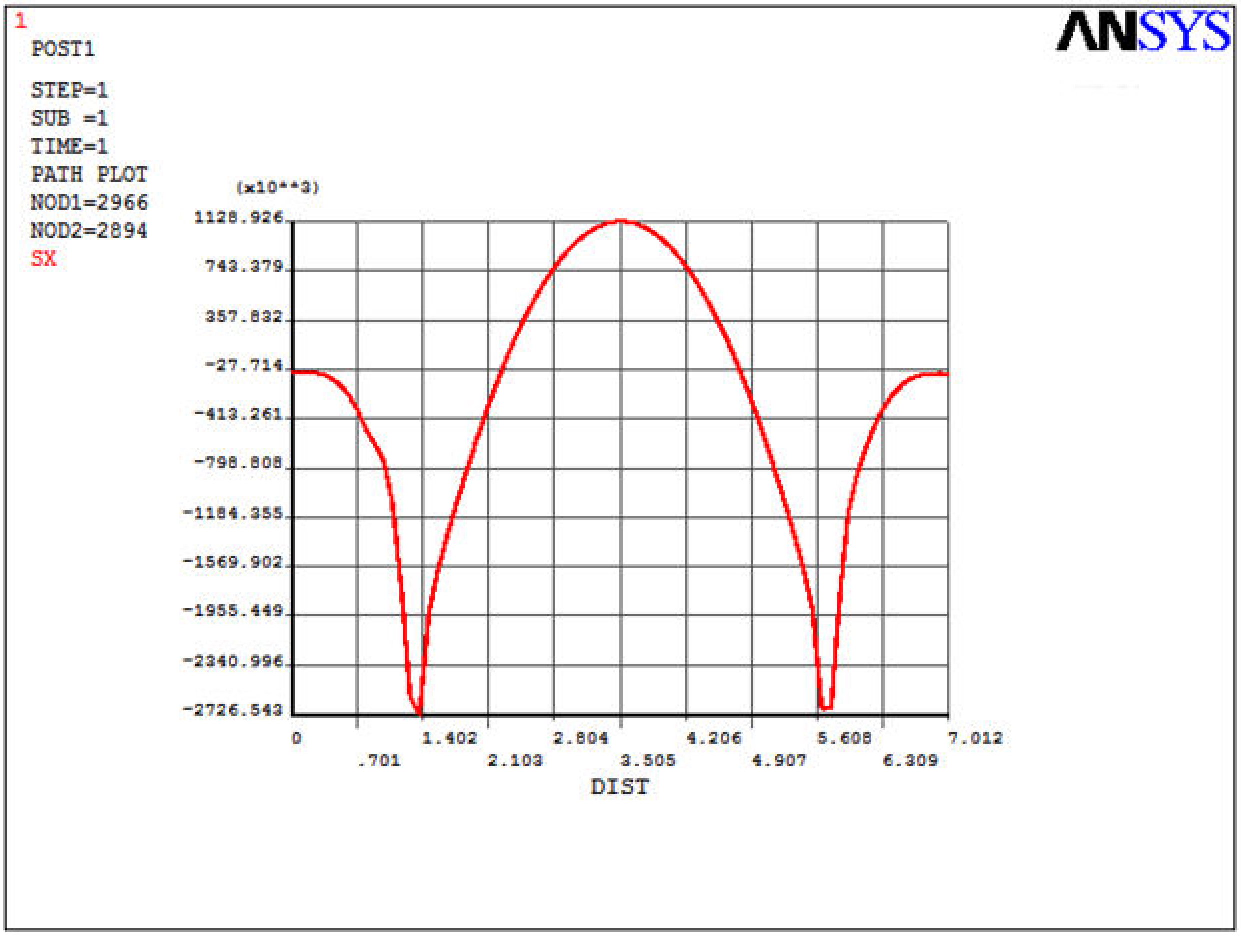
Maximum compressive stress occurs at a distance of X=1m as shown in graph which is the location where haunch ends.

Maximum tensile stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.2.4 Box Culvert with haunch size 1.5T:

Table 17: X-Direction stresses for Box Culvert with haunch size 1.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.129
Maximum compressive stress	2.726



Graph 4.9 X-direction stresses along bottom fiber for haunch size 1.5T

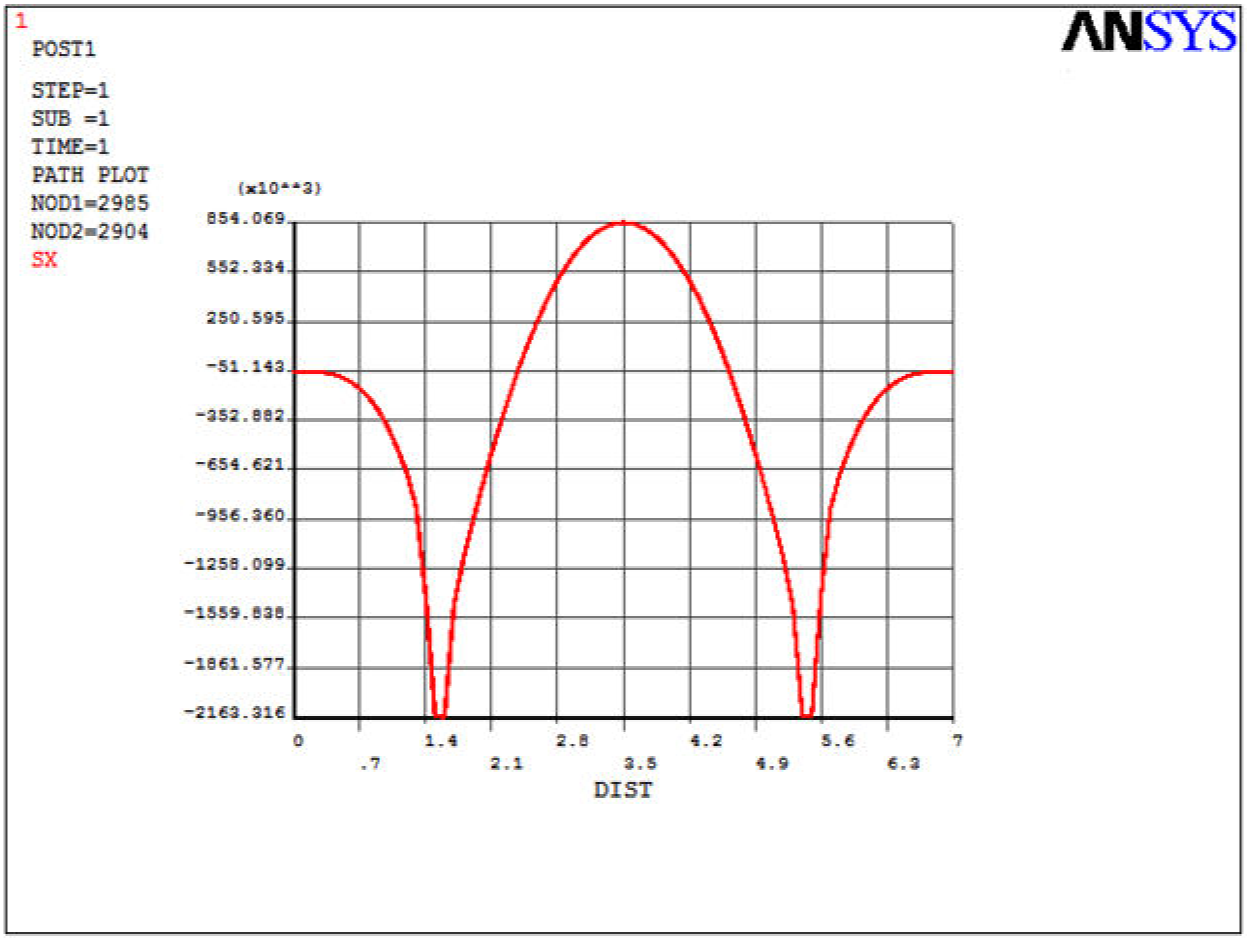
Maximum compressive stress occurs at a distance of X=1.3m as shown in graph which is the location where haunch ends.

Maximum compressive stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.2.5 Box Culvert with haunch size 2T:

Table 18: X-Direction stresses for Box Culvert with haunch size 2T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	0.854
Maximum compressive stress	2.163



Graph 4.10 X-direction stresses along bottom fiber for haunch size 2.0T

Maximum tensile stress occurs at a distance of X=1.5m as shown in graph which is the location where haunch ends.

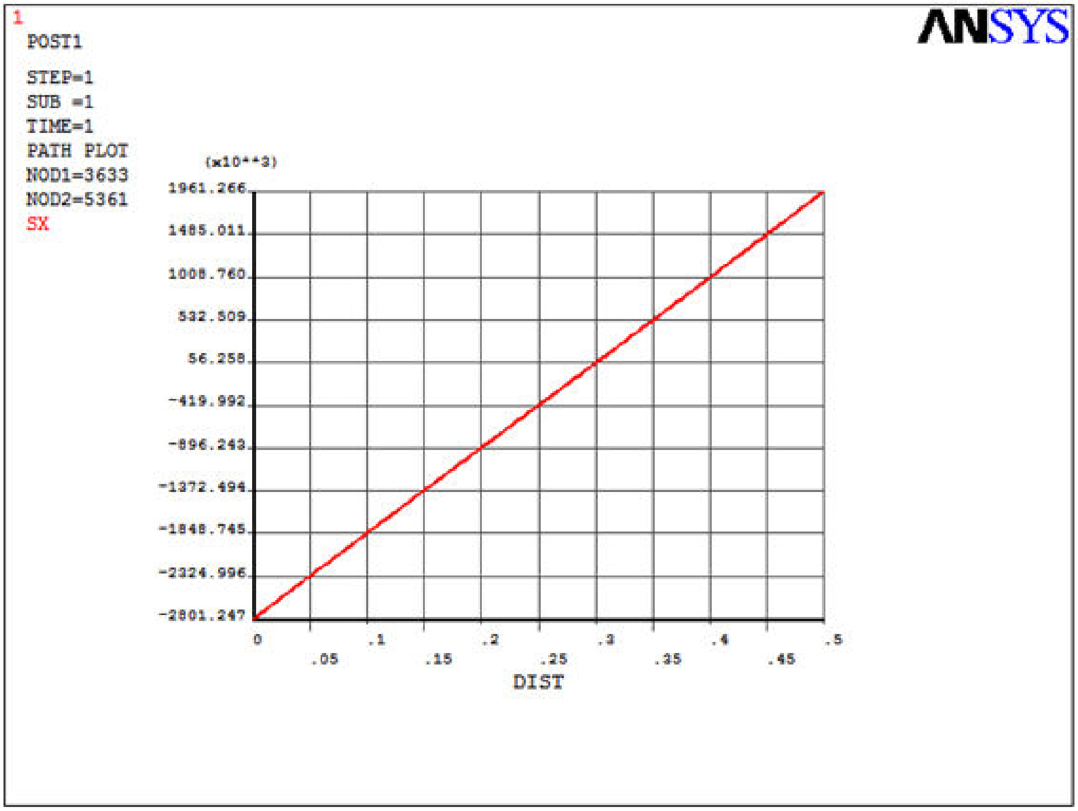
Maximum compressive stress along this path occurs at a distance X=3.5m which is the location at mid span.

4.4.3 X-Direction stresses (stresses due to M_z) at X =3.5 on graph along the thickness

4.4.3.1 Box Culvert without haunch:

Table 19: X-direction stresses along thickness at X =3.5 for no haunch

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.961
Maximum compressive stress	2.801



Graph 4.11 X-direction stresses along thickness at X =3.5 for no haunch

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{1.961}{2.801} = \frac{X}{0.5-X}$ which gives X = 206mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

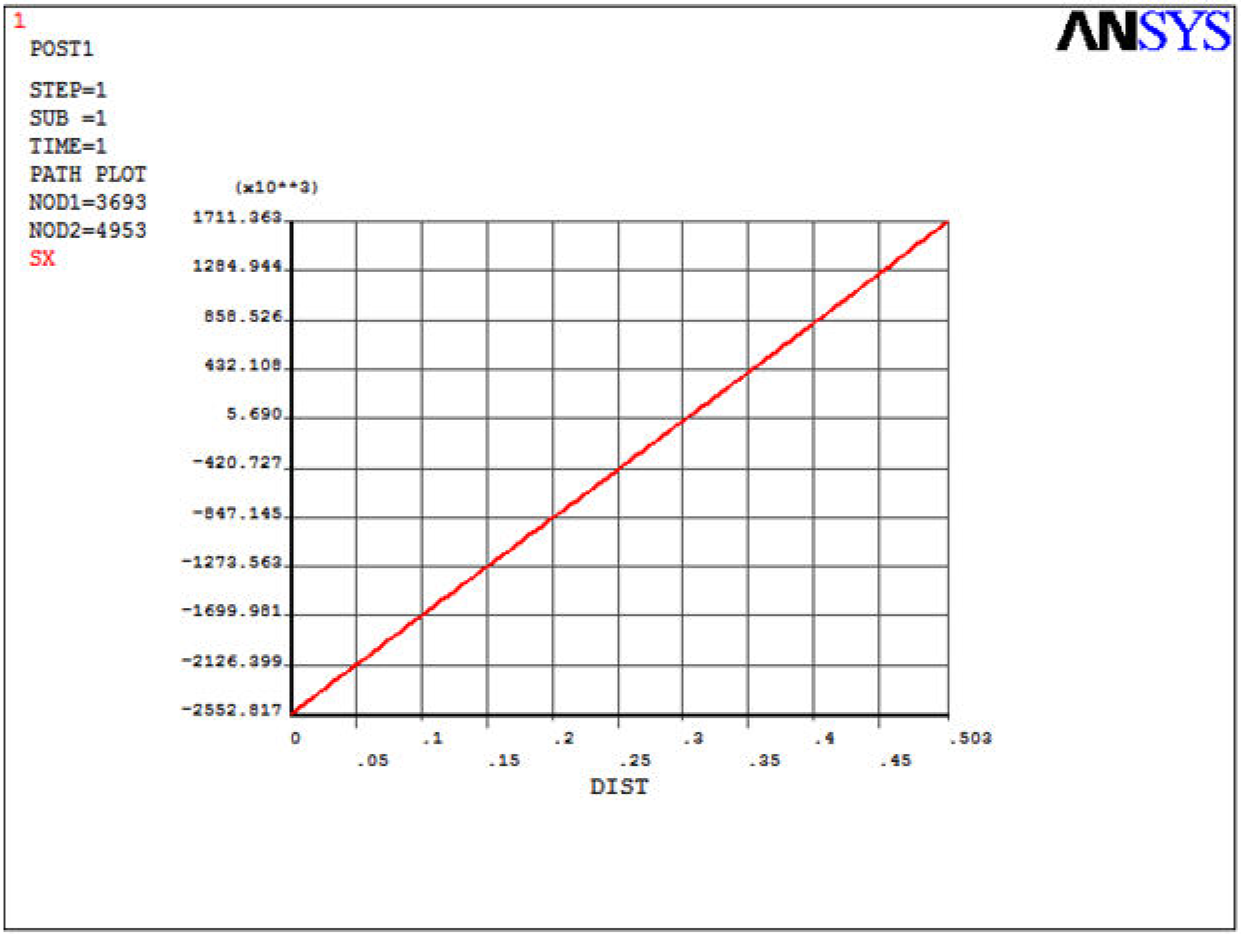
Where, $\sigma = 1.961$ N/mm^2, $I = 1.042*10^{10}$ mm^4 and $y_b = 206$

Bending moment M = 99.192kNm

4.4.3.2 Box Culvert with haunch size 0.5T:

Table 20: X-direction stresses along thickness at X =3.5 for haunch size 0.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.711
Maximum compressive stress	2.552



Graph 4.12 X-direction stresses along thickness at X =3.5 for haunch size 0.5T

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{1.711}{2.552} = \frac{X}{0.5-X}$ which gives X = 200.6mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

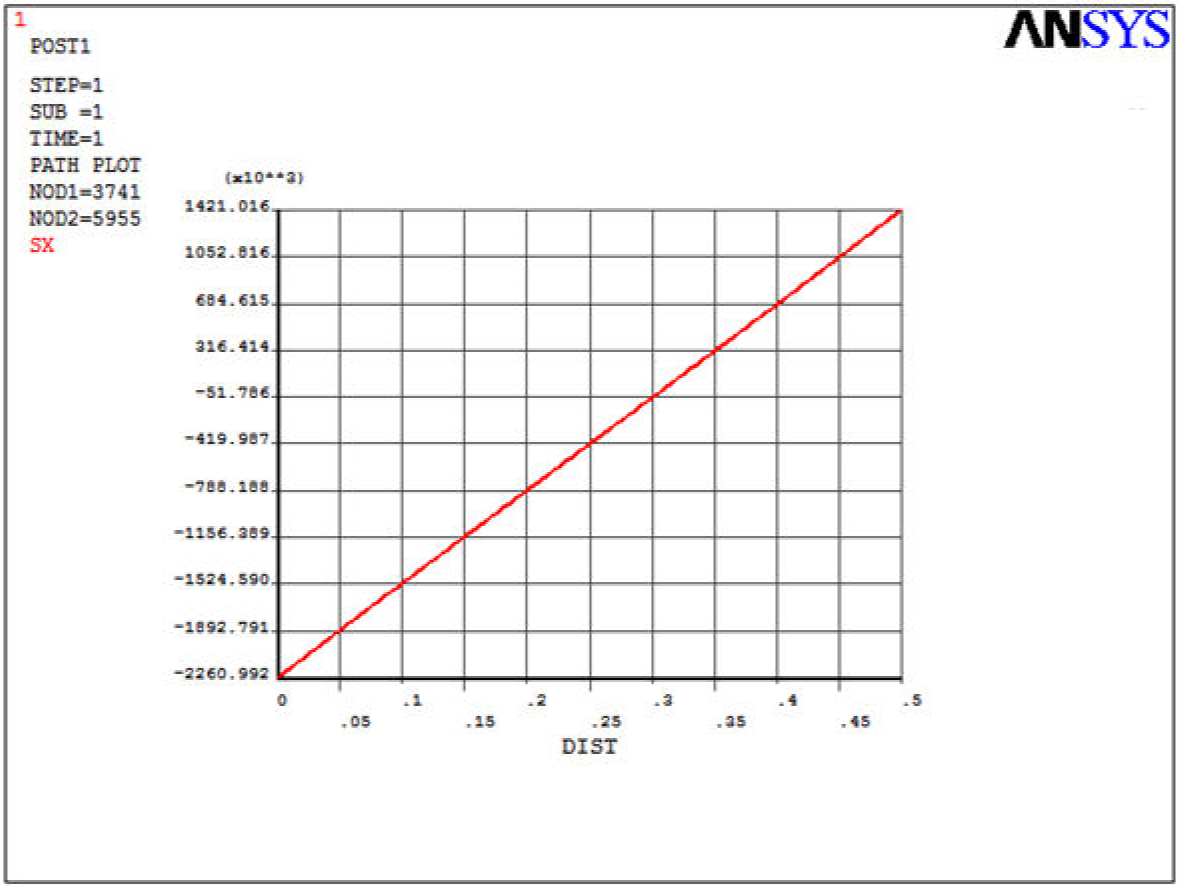
Where, σ = 1.711 N/mm^2, I = 1.042*10^{10}mm^4 and y_b = 200.6

Bending moment M = 88.87 kNm

4.4.3.3 Box Culvert with haunch size 1T:

Table 21: X-direction stresses along thickness at X =3.5 for haunch size 1T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.421
Maximum compressive stress	2.260



Graph 4.13 X-direction stresses along thickness at X =3.5 for haunch size 1.0T

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{1.421}{2.260} = \frac{X}{0.5-X}$ which gives X = 193mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

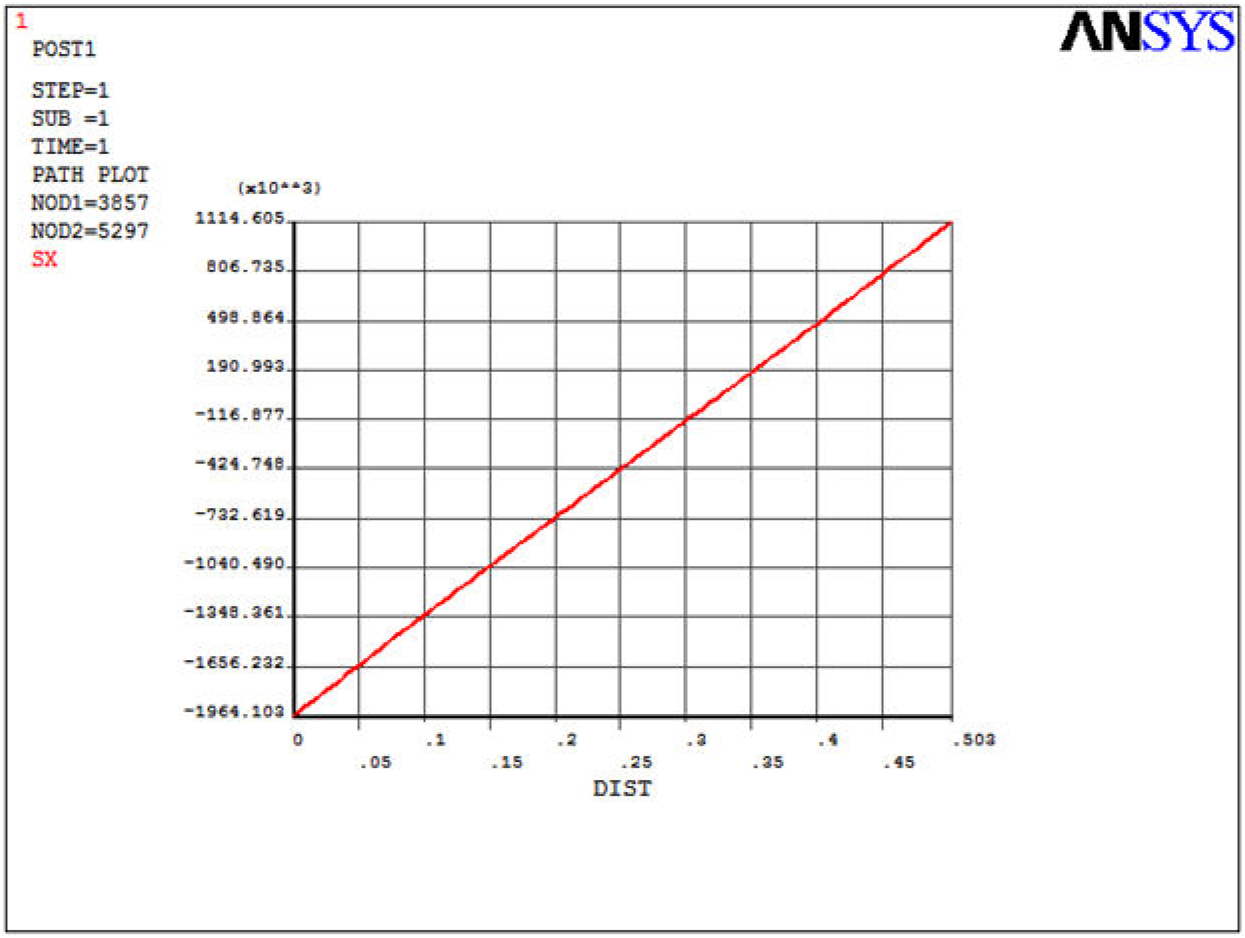
Where, $\sigma = 1.421$ N/mm^2, I = $1.042 * 10^{10}$mm^4 and $y_b = 193$

Bending moment M = 76.72 kNm

4.4.3.4 Box Culvert with haunch size 1.5T:

Table 22: X-direction stresses along thickness at X =3.5 for haunch size 1.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.114
Maximum compressive stress	1.964



Graph 4.14 X-direction stresses along thickness at X =3.5 for haunch size 1.5T

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{1.114}{1.964} = \frac{X}{0.5-X}$ which gives X = 180.9mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

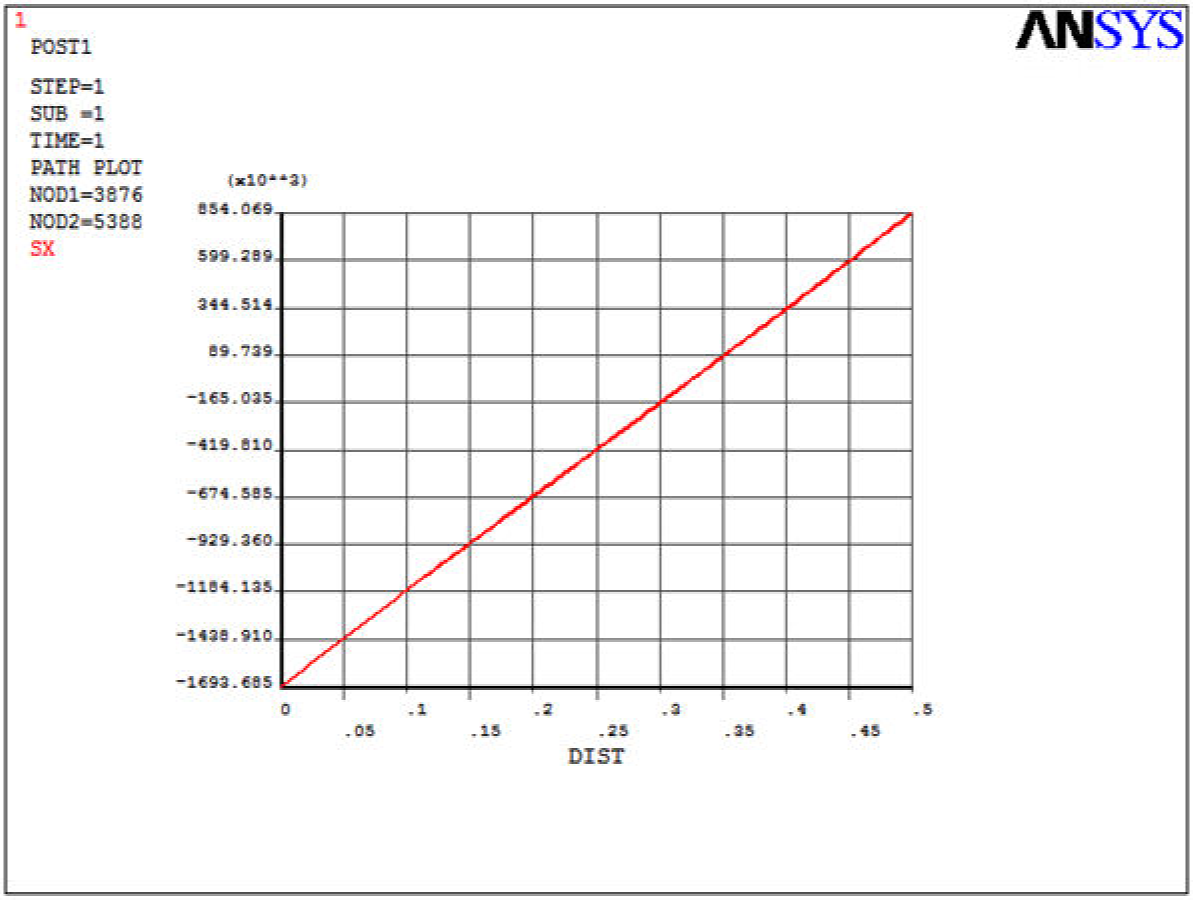
Where, σ = 1.114 N/mm^2, I = 1.042*10^{10}mm^4 and y_b = 180.9

Bending moment M = 64.16 kNm

4.4.3.5 Box Culvert with haunch size 2T:

Table 23: X-direction stresses along thickness at X =3.5 for haunch size 2T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	0.854
Maximum compressive stress	1.693



Graph 4.15 X-direction stresses along thickness at X =3.5 for haunch size 2.0T

Depth of plane where bending stresses are zero = X from bottom

From graph, $\frac{0.854}{1.693} = \frac{X}{0.5-X}$ which gives X = 167.6mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

Where, $\sigma = 0.854$ N/mm^2, $I = 1.042*10^{10}$mm^4 and $y_b = 167.6$

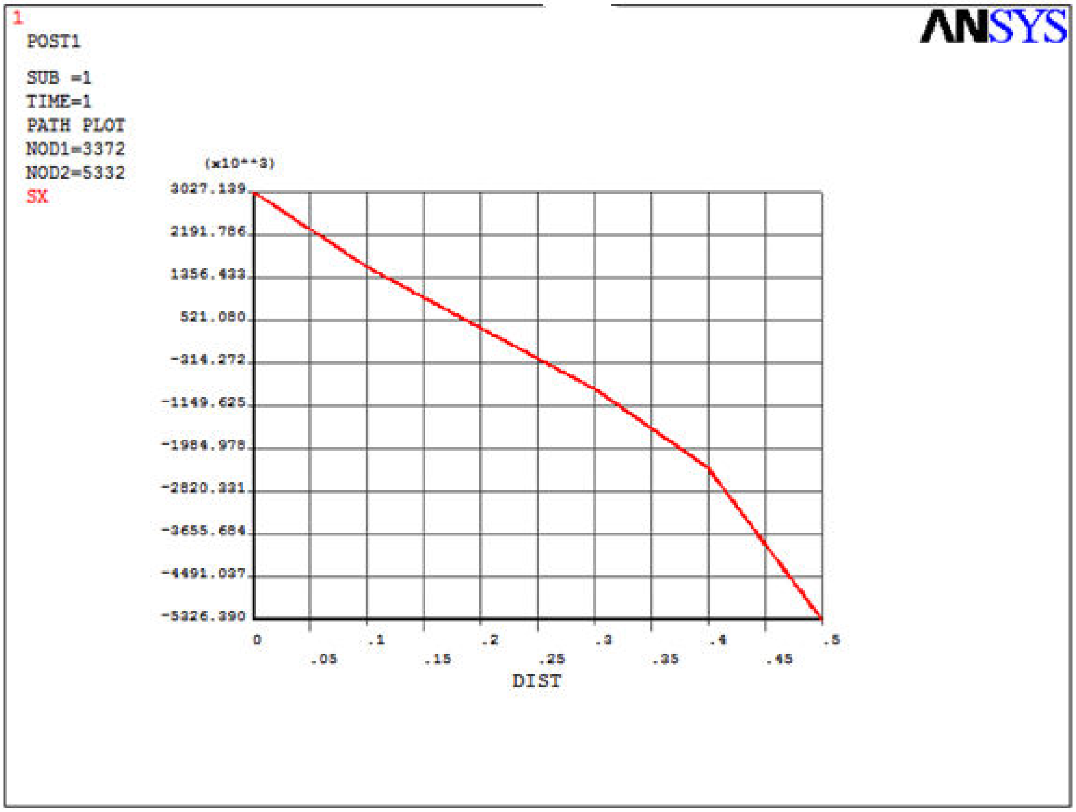
Bending moment M = 53.09 kNm

4.4.4 X-Direction stresses (stresses due to M_z) at the end of haunch along thickness

4.4.4.1 Box Culvert without haunch:

Table 24: X-direction stresses along thickness at corner for no haunch

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	3.027
Maximum compressive stress	5.326



Graph 4.16 X-direction stresses along thickness at corner for no haunch

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{3.027}{5.326} = \frac{X}{0.5-X}$ which gives X = 181.2mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

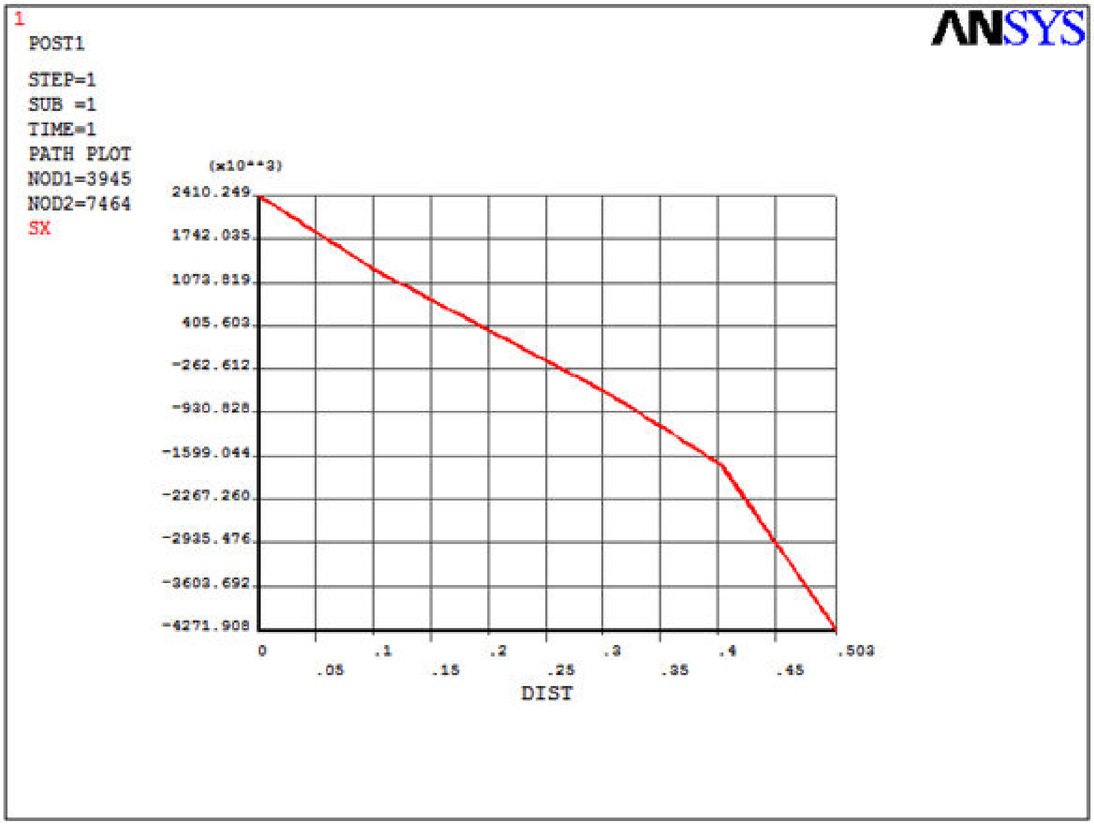
Where, $\sigma = 3.027$ N/mm^2, $I = 1.042*10^{10}$mm^4 and $y_t = 181.2$

Bending moment M = 174.06kNm

4.4.4.2 Box Culvert with haunch size 0.5T:

Table 25: X-direction stresses along thickness at corner for haunch size 0.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	2.410
Maximum compressive stress	4.271



Graph 4.17 X-direction stresses along thickness at corner for haunch size 0.5T

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{2.410}{4.271} = \frac{X}{0.5-X}$ which gives X = 180.3mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives $M = \frac{\sigma}{y}$ *I

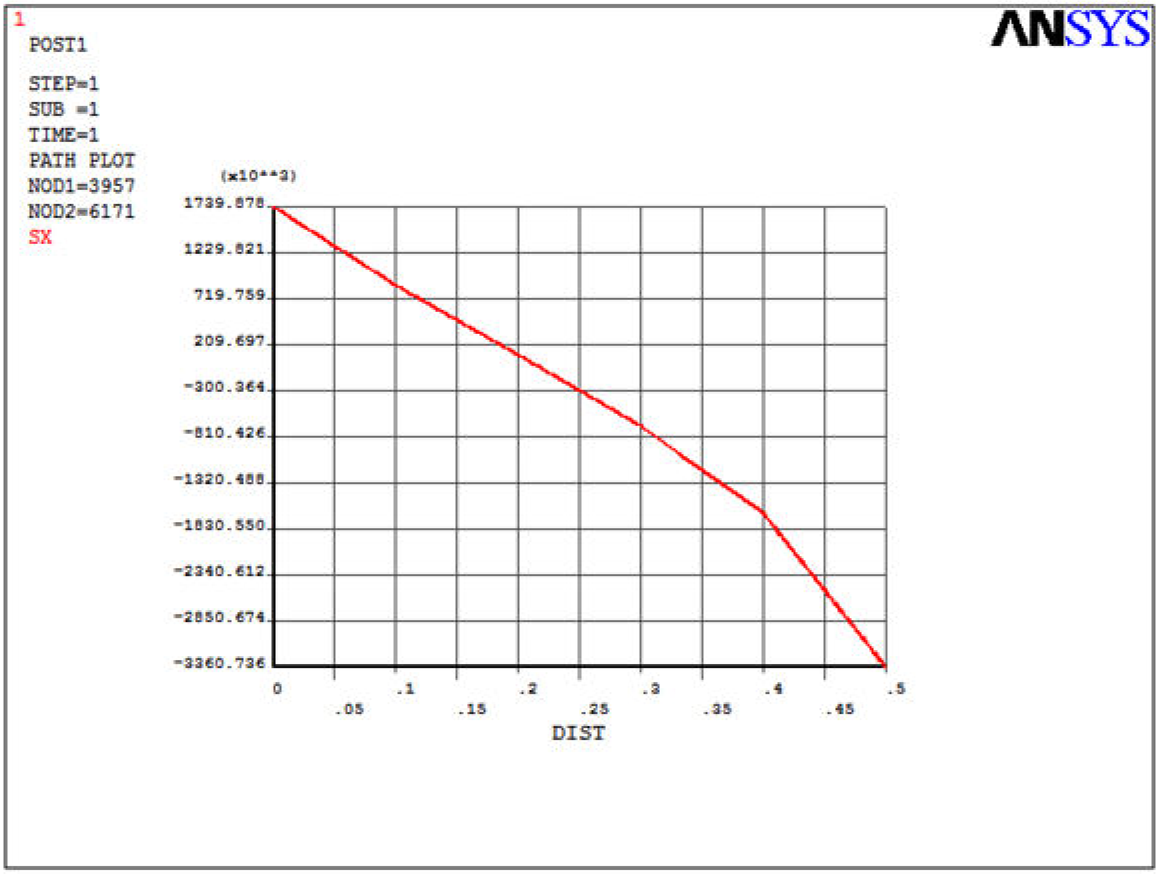
Where, σ =2.410 N/mm^2, $I = 1.042*10^{10}$mm^4 and $y_b = 180.3$

Bending moment M = 139.23 kNm

4.4.4.3 Box Culvert with haunch size 1T:

Table 26: X-direction stresses along thickness at corner for haunch size 1T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.739
Maximum compressive stress	3.360



Graph 4.18 X-direction stresses along thickness at corner for haunch size 1.0T

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{1.739}{3.360} = \frac{X}{0.5-X}$ which gives X = 170.5mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

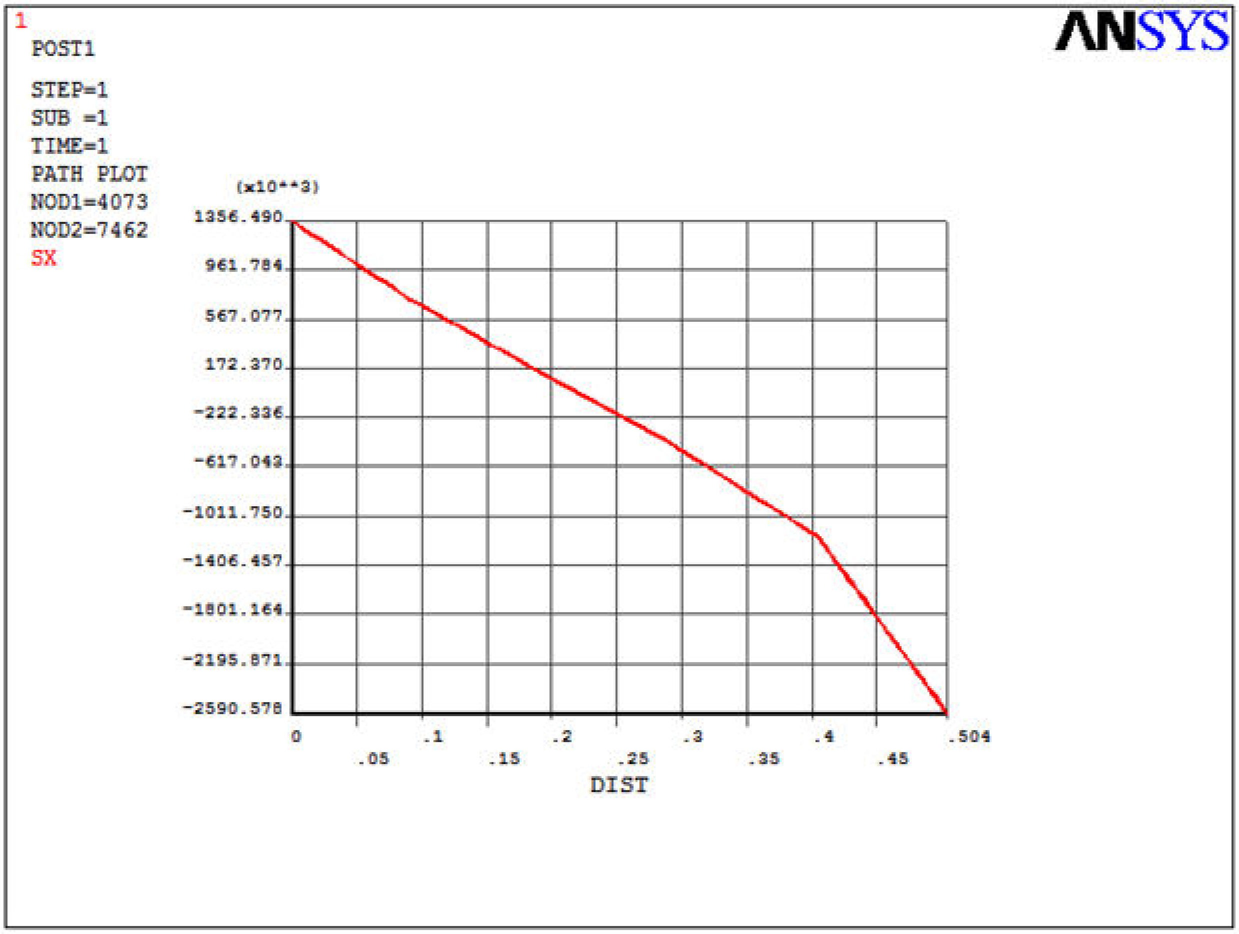
Where, $\sigma = 1.739$ N/mm^2, I = $1.042*10^{10}$mm^4 and $y_b = 170.5$

Bending moment M = 106.27 kNm

4.4.4.4 Box Culvert with haunch size 1.5T:

Table 27: X-direction stresses along thickness at corner for haunch size 1.5T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	1.356
Maximum compressive stress	2.590



Graph 4.19 X-direction stresses along thickness at corner for haunch size 1.5T

Depth of plane where bending stresses are zero = X from top

From graph, $\frac{1.356}{2.590} = \frac{X}{0.5-X}$ which gives X = 171.8mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

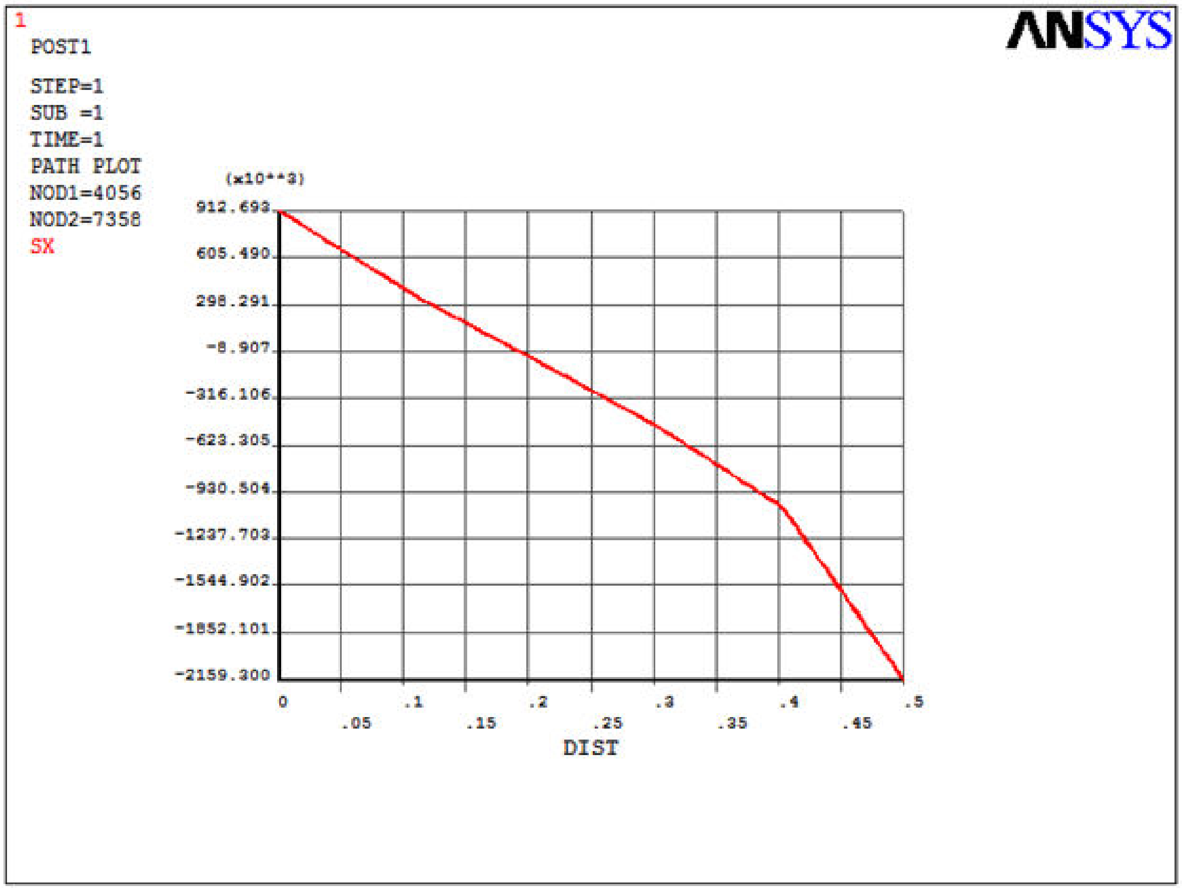
Where, $\sigma = 1.356$ N/mm^2, I = $1.042*10^{10}$mm^4 and $y_b = 171.8$

Bending moment M = 82.24 kNm

4.4.4.5 Box Culvert with haunch size 2T:

Table 28: X-direction stresses along thickness at corner for haunch size 2T

Type of stresses	Stress (N/mm^2)
Maximum Tensile stress	0.912
Maximum compressive stress	2.159



Graph 4.20 X-direction stresses along thickness at corner for haunch size 2.0T

Depth of plane where bending stresses are zero = X from bottom

From graph, $\frac{0.912}{2.159} = \frac{X}{0.5-X}$ which gives X = 137.5mm

Therefore bending moment at this section, $\frac{M}{I} = \frac{\sigma}{y}$ which gives M = $\frac{\sigma}{y}$ *I

Where, $\sigma = 0.912$ N/mm^2, $I = 1.042*10^{10}$mm^4 and $y_b = 137.5$

Bending moment M = 69.11kNm

Maximum span i.e positive Bending moment = 52.99kNm

Maximum end i.e –ve Bending moment = 48.58kNm

Chapter 5

Results And Discussion

5.1 Maximum X-direction stresses due to bending about Z axis:

Table 29: Maximum X-direction stresses due to bending about Z axis

Case No.	Type of Box Culvert	Maximum X-direction stresses (N/mm^2)		% Reduction w.r.t first case	
		Compressive	Tensile	Compressive	Tensile
1	Without Haunch	6.89	3.10	-	-
2	Haunch size 0.5T	4.91	2.46	28.73	20.64
3	Haunch size 1.0T	4.11	1.88	40.34	39.35
4	Haunch size 1.5T	3.31	1.38	51.9	55.48
5	Haunch size 2.0T	2.72	0.9523	60.52	68.28

5.2 Maximum X-direction stresses along top slab top fiber due to bending about Z axis:

Table 30: Maximum X-direction stresses along top slab top fiber due to bending about Z axis

Case No.	Type of Box Culvert	Maximum X-direction stresses (N/mm^2)		% Reduction w.r.t first case	
		Compressive	Tensile	Compressive	Tensile
1	Without Haunch	2.801	3.029	-	-
2	Haunch size 0.5T	2.552	2.419	8.9	20.13
3	Haunch size 1.0T	2.260	1.851	19.31	38.89
4	Haunch size 1.5T	1.971	1.365	29.63	55.00
5	Haunch size 2.0T	1.693	0.943	39.55	68.86

From the analysis of Box culverts with varying haunch size it has been observed maximum flexural tensile stresses on top fiber in case of no haunch is 3.029 N/mm^2, for haunch size 0.5

times thickness of wall it is 2.419 N/mm^2, for haunch size 1 times thickness of wall it is 1.851 N/mm^2 for haunch size 1.5 times thickness of wall it is 1.365N/mm^2 and for haunch size 2 times thickness of wall it is 1.0.943 N/mm^2 similarly maximum flexural compressive stresses on top fibre in case of no haunch is 2.801 N/mm^2, for haunch size 0.5 times thickness of wall it is 2.552 N/mm^2, for haunch size 1 times thickness of wall it is 2.260 N/mm^2 for haunch size 1.5 times thickness of wall it is 1.971N/mm^2 and for haunch size 2 times thickness of wall it is 1.693 N/mm^2. From these results it has been observed that there is 68% reduction in tensile stresses of top fibre and 39% reduction in compressive stresses of top fibre.

5.3 Maximum X-direction stresses along top slab bottom fiber due to bending about Z axis:

Table 31: Maximum X-direction stresses along top slab bottom fiber due to bending about Z axis

Case No.	Type of Box Culvert	Maximum X-direction stresses (N/mm^2)		% Reduction w.r.t first case	
		Compressive	Tensile	Compressive	Tensile
1	Without Haunch	5.326	1.961	-	-
2	Haunch size 0.5T	4.271	1.711	19.80	12.74
3	Haunch size 1.0T	3.360	1.421	36.91	27.53
4	Haunch size 1.5T	2.726	1.129	48.82	42.42
5	Haunch size 2.0T	2.163	0.854	59.38	56.45

Maximum flexural tensile stresses on bottom fibre in case of no haunch is 1.961 N/mm^2, for haunch size 0.5 times thickness of wall it is 1.711 N/mm^2, for haunch size 1 times thickness of wall it is 1.421 N/mm^2 for haunch size 1.5 times thickness of wall it is 1.129N/mm^2 and for haunch size 2 times thickness of wall it is 1.0.854 N/mm^2 similarly maximum flexural compressive stresses on bottom fibre in case of no haunch is 5.326 N/mm^2, for haunch size 0.5 times thickness of wall it is 4.271 N/mm^2, for haunch size 1 times thickness of wall it is 3.360 N/mm^2 for haunch size 1.5 times thickness of wall it is 2.726N/mm^2 and for haunch size 2 times thickness of wall it is 2.163 N/mm^2. From these results it has been observed that there is 56%

reduction in tensile stresses of bottom fibre and 59% reduction in compressive stresses of bottom fibre.

5.4 Maximum positive and negative Bending Moments:

Table 32: Maximum positive and negative Bending Moments

Case No.	Type of Box Culvert	Maximum positive Moment (kNm)	Maximum negative Moment (kNm)
1	Without Haunch	99.2	174.06
2	Haunch size 0.5T	88.87	139.23
3	Haunch size 1.0T	76.72	106.27
4	Haunch size 1.5T	64.16	82.24
5	Haunch size 2.0T	53.09	69.11

5.5 Design of Box Culvert:

5.5.1 Box Culvert without Haunches:

Maximum negative bending moment = 174.06

Maximum positive bending moment = 99.2

For M20 grade concrete and Fe415 steel,

$\sigma_{st} = 190 \text{ N/mm}^2$, $\sigma_{cbc} = 6.7\text{N/mm}^2$

Neutral axis depth factor = $(m\sigma_{cbc} / m\sigma_{cbc} + \sigma_{st}) = 0.33$

Lever arm factor (j)= 1-(k/3) = 0.89

Moment resisting factor = 0.5 $(\sigma_{cbc} \times j \times k) = 0.985$

Depth of section = $\sqrt[2]{\frac{M}{Rb}}$ = 424 mm

Assume an cover of 40mm and maximum 20mm diameter bars.

Therefore thickness required = 424+40+(20/2) = 474mm

Area of steel required for negative bending moment = $(M / \sigma_{st} \times j \times d) = 2428 \text{ N/mm}^2$.

Area of steel required for positive bending moment = $(M / \sigma_{st} \times j \times d) = 1384 \text{ N/mm}^2$.

Distribution steel required = (0.12×b×d/100) = 568.8mm^2

Provide 12mm dia at 200mm c/c at top and bottom for distribution steel at top and bottom

Total No of 12mm bars of 7.5m required for distribution steel = (2×4×6×568.8/113)

= 242

5.5.2 Box Culvert with haunch size 0.5T:

Maximum negative bending moment = 139.23

Maximum positive bending moment = 88.87

For M20 grade concrete and Fe415 steel,

σ_{st} = 190 N/mm^2, σ_{cbc} = 6.7N/mm^2

Neutral axis depth factor = ($m\sigma_{cbc}$ / $m\sigma_{cbc} + \sigma_{st}$) = 0.33

Lever arm factor (j)= 1-(k/3) = 0.89

Moment resisting factor = 0.5 (σ_{cbc}×j×k) = 0.985

Depth of section = $\sqrt[2]{\frac{M}{Rb}}$ = 376 mm

Assume an cover of 40mm and maximum 20mm diameter bars.

Therefore thickness required = 376+40+(20/2) = 426mm

Area of steel required for negative bending moment = (M / σ_{st}×j×d) = 2189 mm^2.

Area of steel required for positive bending moment = (M / σ_{st}×j×d) = 1397 mm^2.

Distribution steel required = (0.12×b×d/100) = 512mm^2

Provide 12mm dia at 220mm c/c at top and bottom for distribution steel at top and bottom

Total No of 12mm bars of 7.5m required for distribution steel = (2×4×6×512/113)

= 216

5.5.3 Box Culvert with haunch size 1.0T:

Maximum negative bending moment = 106.27

Maximum positive bending moment = 76.72

For M20 grade concrete and Fe415 steel,

σ_{st} = 190 N/mm^2, σ_{cbc} = 6.7N/mm^2

Neutral axis depth factor = ($m\sigma_{cbc}$ / $m\sigma_{cbc} + \sigma_{st}$) = 0.33

Lever arm factor (j)= 1-(k/3) = 0.89

Moment resisting factor = 0.5 (σ_{cbc}×j×k)

Depth of section = $\sqrt[2]{\frac{M}{Rb}}$ = 328 mm

Assume an cover of 40mm and maximum 20mm diameter bars.

Therefore thickness required = 328+40+(20/2) = 378mm

Area of steel required for negative bending moment = (M / σ_{st}×j×d) = 1916 N/mm^2.

Area of steel required for positive bending moment = (M / σ_{st}×j×d) = 1377 N/mm^2.

Distribution steel required = (0.12×b×d/100) = 453mm^2

Provide 10mm dia at 175mm c/c at top and bottom for distribution steel at top and bottom

Total No of 10mm bars of 7.5m required for distribution steel = (2×4×6×453/78.5)

= 276

5.5.4 Box Culvert with haunch size 1.5T:

Maximum negative bending moment = 82.24

Maximum positive bending moment = 64.16

For M20 grade concrete and Fe415 steel,

σ_{st} = 190 N/mm^2, σ_{cbc} = 6.7N/mm^2

Neutral axis depth factor = (mσ_{cbc} / mσ_{cbc} + σ_{st}) = 0.33

Lever arm factor (j)= 1-(k/3) = 0.89

Moment resisting factor = 0.5 (σ_{cbc}×j×k)

Depth of section = $\sqrt[2]{\frac{M}{Rb}}$ = 290 mm

Assume an cover of 40mm and maximum 20mm diameter bars.

Therefore thickness required = 290+40+(20/2) = 340 mm

Area of steel required for negative bending moment = (M / σ_{st}×j×d) = 1677 N/mm^2.

Area of steel required for positive bending moment = (M / σ_{st}×j×d) = 1308 N/mm^2.

Distribution steel required = (0.12×b×d/100) = 408mm^2

Provide 12mm dia at 220mm c/c at top and bottom for distribution steel at top and bottom

Total No of 10mm bars of 7.5m required for distribution steel = (2×4×7.5×408/78.5)

= 248

5.5.5 Box Culvert with haunch size 2.0T:

Maximum negative bending moment = 68.11

Maximum positive bending moment = 53.09

For M20 grade concrete and Fe415 steel,

$\sigma_{st} =$ 190 N/mm^2, $\sigma_{cbc} =$ 6.7N/mm^2

Neutral axis depth factor = $(m\sigma_{cbc} / m\sigma_{cbc} + \sigma_{st}) = 0.33$

Lever arm factor (j)= 1-(k/3) = 0.89

Moment resisting factor = 0.5 (σ_{cbc}×j×k) = 0.985

Depth of section = $\sqrt[2]{\frac{M}{Rb}}$ = 260 mm

Assume an cover of 40mm and maximum 20mm diameter bars.

Therefore thickness required = 260+40+(20/2) = 310mm

Area of steel required for negative bending moment = (M / σ_{st}×j×d) = 1550 N/mm^2.

Area of steel required for negative bending moment = (M / σ_{st}×j×d) = 1208 N/mm^2.

Distribution steel required = (0.12×b×d/100) = 372mm^2

Provide 12mm dia at 200mm c/c at top and bottom for distribution steel

Total No of 10mm bars of 7.5m required for distribution steel = (2×4×6×372/78.5)

= 220

Table 33: positive and negative reinforcement and volume of concrete for one meter width of box culvert

Type of Box Culvert	positive Reinforcement (mm^2)		negative Reinforcement (mm^2)		Volume of Concrete per meter width (m^3)
	A_{st}	N	A_{st}	N	
Without Haunch	1384	7#16φ	2428	8#20φ	12.32
Haunch size 0.5T	1397	7#16φ	2189	7#20φ	11.21
Haunch size 1.0T	1377	7#16φ	1916	6#20φ	10.33
Haunch size 1.5T	1308	7#16φ	1677	5#20φ	9.96
Haunch size 2.0T	1208	6#16φ	1550	5#20φ	10.06

Note: Where 'N' is no of bars required per meter width of box culvert for one wall

Table 34: positive and negative reinforcement and volume of concrete for 7.5m width of box culvert

Type of Box Culvert	positive Reinforcement (mm^2)		negative Reinforcement (mm^2)		Volume of Concrete for 7.5m width (m^3)
	L (mm)	N	L (mm)	N	
Without Haunch	7500	52#16φ	8950	60#20φ	92.4
Haunch size 0.5T	7500	52#16φ	8852	52#20φ	84.0
Haunch size 1.0T	7500	52#16φ	8756	45#20φ	77.5
Haunch size 1.5T	7500	52#16φ	8680	38#20φ	74.5
Haunch size 2.0T	7500	45#16φ	8620	38#20φ	75.5

Note:

- Where 'N' is no of bars required for 7.5m width of box culvert
- 'L' is the length of bar including development length

5.6 Quantity of steel required:

5.6.1 Box culvert without haunch

No. of bars required for four walls for positive reinforcement = 4×52#16φ =208#16φ

No. of bars required for four walls for negative reinforcement = 4×60#20φ =240#20φ

NO of 12mm bars required for distribution steel = 242

Volume of steel in = 0.335+0.675+0.205=1.215m^3

Unit weight of steel = 78.5kN/m^3

Quantity of steel required = (78.5×1.215×10) = 953.7 quintal

5.6.2 Box culvert with haunch size size 0.5T

No. of bars required for four walls for positive reinforcement = 4×52#16φ =208#16φ

No. of bars required for four walls for negative reinforcement = 4×52#20φ =208#20φ

No of 112mm bars required for distribution steel = 216

Provide 12mm dia bars at 200mm c/c for haunch reinforcement

No. of 12mm dia bars of length 1500mm for haunch reinforcement = 144

No. of 12mm dia bars of length 7500mm for haunch reinforcement = 16

Volume of steel in = 0.335+0.578+0.183+0.0244+0.0135=1.130m^3

Unit weight of steel = 78.5kN/m^3

Quantity of steel required in quintal = (78.5×1.130×10) = 887.05quintal

5.6.3 Box culvert with haunch size 1.0T

No. of bars required for four walls for positive reinforcement = 4×52#16φ =208#16φ

No. of bars required for four walls for negative reinforcement = 4×45#20φ =180#20φ

No. of 10mm bars required for distribution steel = 276

Provide 12mm dia bars at 200mm c/c for haunch reinforcement

No. of 12mm dia bars of length 2500mm for haunch reinforcement = 144

No. of 12mm dia bars of length 7500mm for haunch reinforcement = 28

Volume of steel in = 0.335+0.495+0.162+0.040+0.0237=1.050m^3

Unit weight of steel = 78.5kN/m^3

Quantity of steel required = (78.5×1.050×10) = 824.25 quintal

5.6.4 Box culvert with haunch size 1.5T

No. of bars required for four walls for positive reinforcement = 4×45#16φ =208#16φ

No. of bars required for four walls for negative reinforcement = 4×38#20φ =152#20φ

No. of 10mm bars required for distribution steel = 248

Provide 12mm dia bars at 200mm c/c for haunch reinforcement

No. of 12mm dia bars of length 3250mm for haunch reinforcement = 144

No. of 12mm dia bars of length 7500mm for haunch reinforcement = 40

Volume of steel in = 0.335+0.414+0.146+0.052+0.0338=0.980m^3

Unit weight of steel = 78.5kN/m^3

Quantity of steel required in quintal = (78.5×0.980×10) = 769.3 quintal

5.6.5 Box culvert with haunch size 2.0T

No. of bars required for four walls for positive reinforcement = 4×45#16φ =180#16φ

No. of bars required for four walls for negative reinforcement = 4×38#20φ =152#20φ

No. of 10mm bars required for distribution steel = 220

Provide 12mm dia bars at 200mm c/c for haunch reinforcement

No. of 12mm dia bars of length 3950mm for haunch reinforcement = 144

No. of 12mm dia bars of length 7500mm for haunch reinforcement = 56

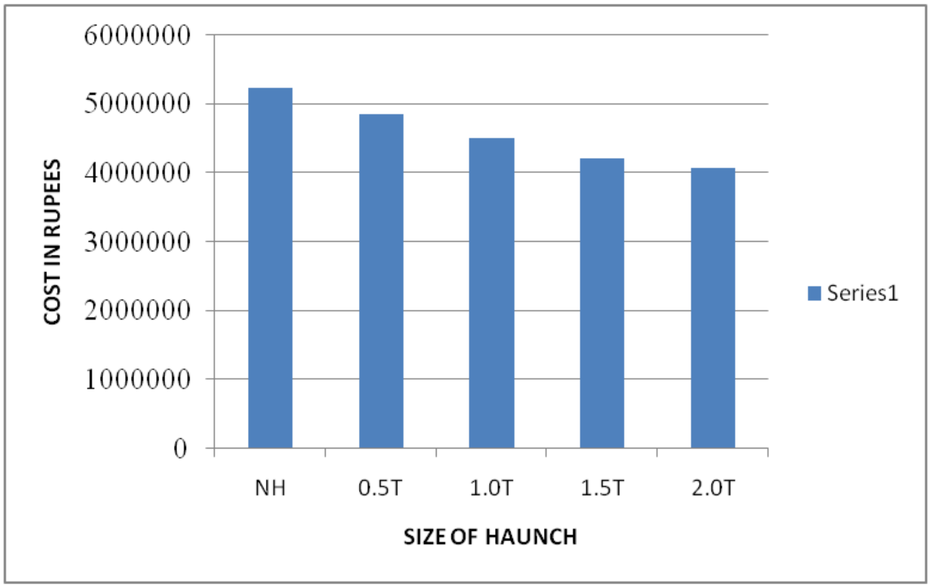
Volume of steel in = 0.290+0.414+0.130+0.0632+0.0473=0.944m^3

Unit weight of steel = 78.5kN/m^3

Quantity of steel required in quintal = (78.5×0.944×10) = 741.04 quintal

Table 35: Total cost of the culverts with different haunch sizes

Type of Box Culvert	Concrete		Steel		Total cost
	Quantity (m^3)	Cost (Rs5000/m^3)	Quantity (Quintal)	Cost (Rs5000/Quintal)	
Without Haunch	92.4	462000	953.7	4768500	5230500
Haunch size 0.5T	84.0	420000	887.0	4435000	4855000
Haunch size 1.0T	77.5	387500	824.2	4121000	4508500
Haunch size 1.5T	74.5	372500	769.0	3845000	4217500
Haunch size 2.0T	75.5	377500	741.0	3705000	4082500



Graph 5.1 Combined Cost comparisons for concrete and steel

From Table No.35 it is found that volume of concrete required for box culvert with no haunch is $92.4m^3$ and this quantity required reduces to $74.5m^3$ for haunch size of 1.5 times thickness of wall. Volume of concrete required for box culvert with haunch size 2.0 times thickness of wall is $75.5m^3$.

It is found from Table No.35 that quantity of steel required for box culvert with no haunches is 953.7 quintal and this quantity reduces to 741 quintal when haunch size increases to 2.0 times thickness of wall also combined cost of concrete and steel reduces from 52,30,500 rupees to 40,82,500 rupees i.e. decreases by 11,48,000 rupees.

Chapter 6

Comparative Study of Conventional and FEM

6.1 Objective of Project

6.1.1 Comparative study of Deflection of Box Culvert without and with Haunches

Since, project has the design of box culvert in ANSYS and STAADPro which is bases on the concepts of finite element method(FEM) and moment distribution method(MDM) respectively, we can compare between the MDM & FEM which simulate results on different principles (different transfer mechanisms of loads).

6.1.2 Comparative study of results for shear strength of Box Culvert without and with Haunches

Box culverts mainly collapse due to shear force. Hence, box culverts should be designed considering shear strength of the structure. In the project we are enhancing the shear strength of box culvert by giving haunches in the culvert and observing the enhancement of shear strength by comparing box culvert with or without haunches.

6.2 Loads Considered For Design

The design of structures for a RCC box culvert has the detailed analysis of the rigid frame for shear forces, thrusts and moments, due to various types of loading conditions listed below:

6.2.1 Uniform Distributed Load (UDL)

The loads of wearing coat, embankments, and deck slab as well as the track load (including live load) are taken to be uniformly distributed load on the top slab and with the uniform soil reaction from the bottom slab.

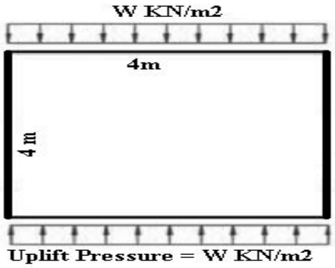


Fig 6.1 Uniform Distributed Load(UDL)

6.2.2 Loads from weight of Side Walls

The loads from self-weight of the two side walls act as concentrated loads and are assumed to produce uniform soil reaction to the bottom slab.

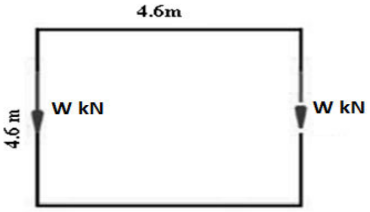


Fig 6.2 Loads from weight of Side Walls

6.2.3 Water Pressure within Culvert

When the water flows full inside the culvert, the distribution of pressure on side walls is assumed to be triangular with a maximum pressure intensity given by P= bγH at the base,

Where, γ = unit weight of water (10 kN/m^3) and 'H' is the depth of flow.

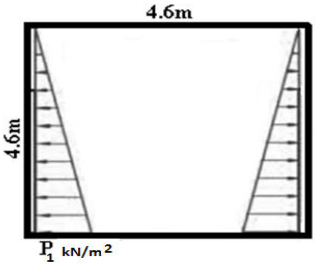


Fig 6.3 Water Pressure within Culvert

6.2.4 Pressure of Earth on Vertical Side Walls

The pressure of earth on the vertical side walls on box culverts is calculated according to the Coulomb's Theory. The distribution of earth pressure on the walls of culvert is shown in figure. where P is the maximum pressure intensity given by $K_a\gamma H$; K_a = Active earth pressure coefficient and γ = unit weight of soil

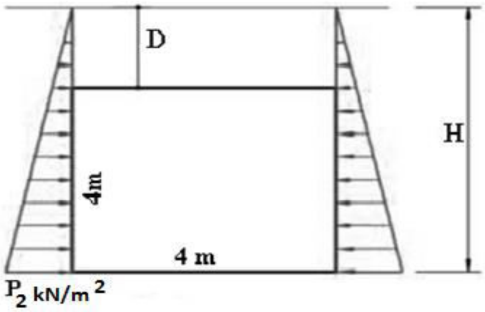


Fig 6.4 Pressure of Earth on Vertical Side Walls

6.2.5 Uniform Lateral Load on Side Walls

Uniform lateral loads on vertical walls should be considered because of the effect of live load surcharge. Also trapezoidal distribution of pressure on side walls due to loading on embankment could be obtained by combining the above two cases.

Q = Surcharge load, P = Pressure intensity (K_aq)

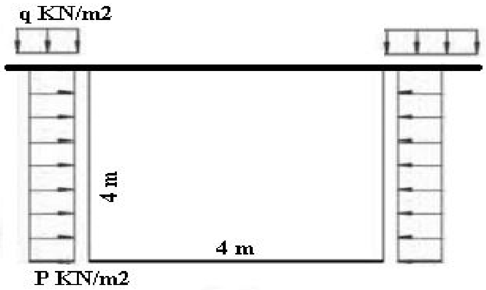


Fig 6.5 Uniform Lateral Load on Side Walls

6.3 Shears, Moments and Thrusts

The box culverts are analyzed for shear forces, moments, and axial thrusts developed because of the different loading conditions through any of the classical methods like moment distribution, slope deflection and finite element method.

6.4 Critical Sections

The critical design moments obtained from the combination of the different loading cases are calculated. The moments in the centre of the span at top and bottom slabs, the support sections and at the centre of the side vertical walls are determined by suitably combining the various loading patterns. The maximum moments generally develop due to the following combinations:

a) When the culvert is empty and the top slab supports the dead and live load.
b) When the culvert is running full and the top slab supports the dead and live loads.
c) When the culvert is running full and the sides of the culvert do not carry the live load.

The slabs of the box culvert has fillets at the inside corners and are reinforced on both faces.

6.5 Experimental Investigation

6.5.1 Box Culvert without Haunches

Box Culvert of size 4m X 4m having thickness of 0.3m. Using M25 concrete and Fe 415 steel, unit weight of soil is 18 KN/m^3 with angle of repose 30^o (sand)

Loads applied on Box Culvert:[12]

a) Given Loads:

On Top Slab, Dead load of 2 kN/m and Live Load of 4 kN/m and on Side Slabs and Bottom Slab, impact pressure of water 2.5 kN/m

b) Loads Calculated:

Self-weight of Top/Bottom Slab is 7.5 kN/m and of Side Slabs is 30 kN (15 KN at each vertices)

Resulting Uplift pressure on Bottom Slab is 37 kN/m

Maximum pressure intensity of hydrostatic pressure by water flowing inside box culvert on inner side of Side Slabs is 40 kN/m

Maximum pressure intensity of linear varying load by soil on outside of Side Slabs is 27.6 kN/m

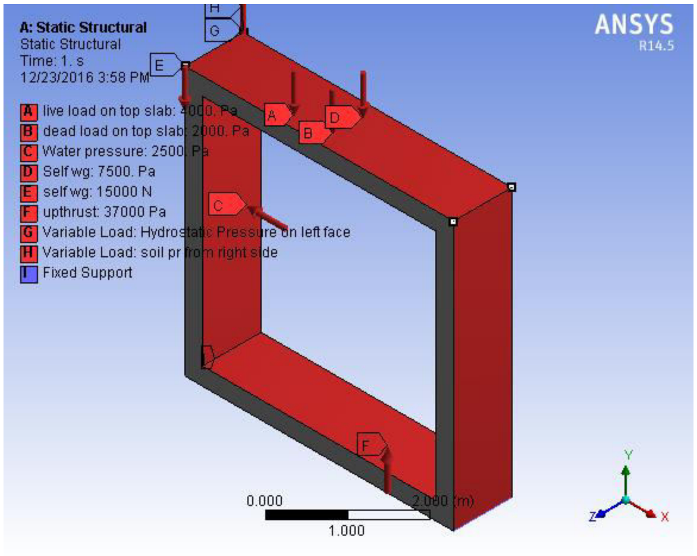


Fig 6.6 Loads on the Culvert without haunch

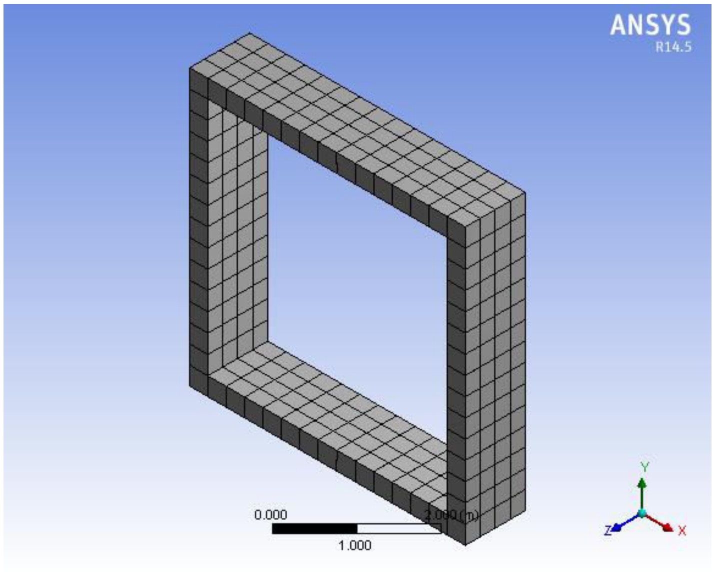


Fig 6.7 Meshing of the Culvert without haunch

ANSYS does not allow for the definition of an additional material model for the tension behavior of concrete. However, if required, an additional stress-strain comparison for compressive behavior of elements can be defined by a hardening model such as Multi-linear Isotropic Hardening. If this is the case, then elasticity modulus must be same as the slope of the initial tangent of the defined stress-strain curve.

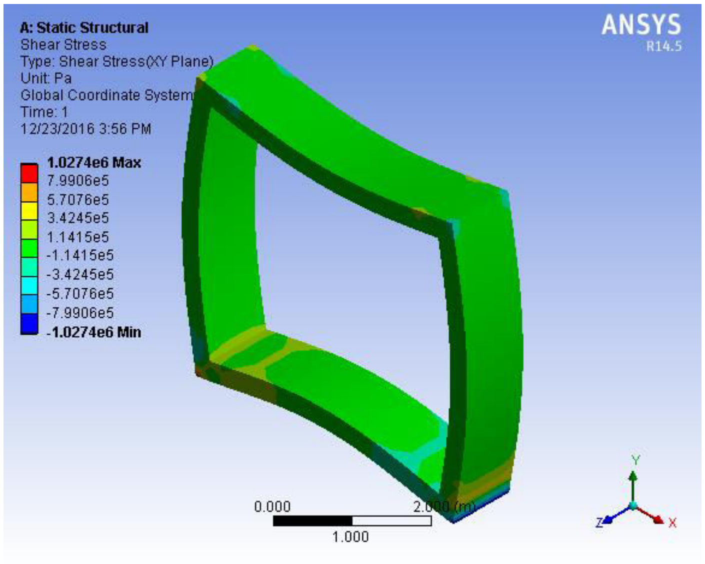


Fig 6.8 Shear Stress on the culvert without haunch

Above figure shows shear stress of box culvert after simulating the box culvert under applied load combinations in ANSYS. We observe that critical shear stress of 1.0274 N/mm^2 acts at the fixed supports. In pre casted structures like here, the monolithic character comes into play wherein the transfer of loads takes place about uniformly to both the end walls.

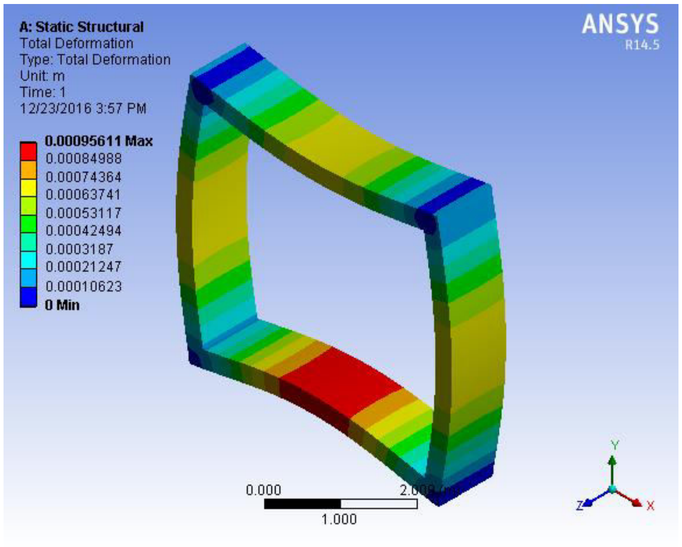


Fig 6.9 Deformation in the culvert without haunch

Above Fig shows deformation in the box culvert after analyzing the culvert under given loads in ANSYS software. We see that maximum deformation of 0.956 mm is at the middle of bottom slab.

6.5.2 Box Culvert with Haunches

 # same conditions for that of culvert without haunches.

Box Culvert of size 4m X 4m having thickness of 0.3m

Length (outer) of Slabs is 3.6m and Length (outer) of Haunches is 0.707m with thickness of 0.3m. Using M25 concrete and Fe 415 steel, unit weight of soil is 18 kN/m^3 with angle of repose 30^o (sand)

Loads applied on Box Culvert:

a) Given Loads:[12]

Top Slab and Haunches with top slab carries Dead load of 2 kN/m and Live Load of 4 kN/m

Side Slabs, Bottom Slab and Haunches with Bottom Slab carries impact pressure of water 2.5 kN/m

b) Loads Calculated:

Self weight of Top/Bottom Slab and Haunches is 7.5 kN/m and of Side Slabs is 27 kN

Resulting Uplift pressure on Bottom Slab is 30 kN/m

Maximum pressure intensity of hydrostatic pressure by water flowing inside box culvert on inner side of Side Slabs is 36.5 kN/m and minimum pressure intensity is 3.5 kN/m

Maximum pressure intensity of linear varying load by soil on outside of Side Slabs is 24.6 kN/m and minimum pressure intensity is 3 kN/m.

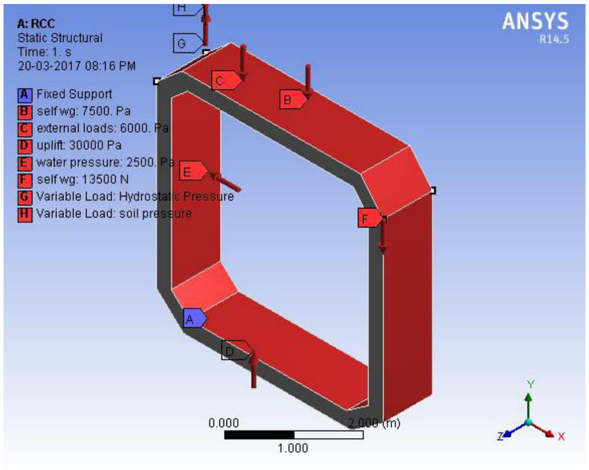


Fig 6.10 Loads on Box Culvert with haunch

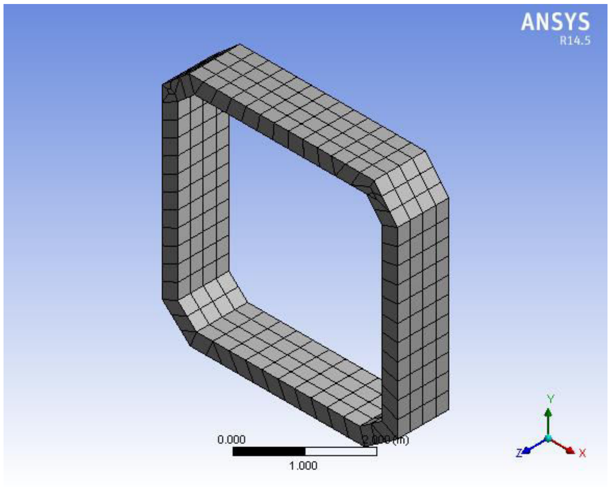


Fig 6.11 Meshing of the culvert with haunch

The modeling of concrete is done using Solid65 element. The element has 8 nodes with 3 degree of freedoms at each node – rotational in the nodal x, y, and z directions. These elements can undergo cracking in three orthogonal directions, plastic deformation, and crushing. The crushing and cracking of concrete by this material model is decided through Solid65 element. A material model is composed of two or more material definitions. Element of concrete material must have material definition and Elastic definition of concrete. In definition of Elasticity, Poisson's ratio and the modulus of elasticity are necessary. The elasticity modulus of concrete is decided by conventional formulae and methods. For Concrete definition, axial tension strength of concrete and shear transfer coefficients between crack surfaces for open and closed cracks are required. If transfer of shear from one crack surface to the other does not exist then the shear transfer coefficient is 0, if it fully exists then the coefficient is 1.0.

For the tension behavior of concrete, ANSYS does not allow for the definition of an additional material model. However, if requested/required, an additional stress-strain relationship for compressive behavior of element can be defined through a hardening model such as Multi-linear Isotropic Hardening. If this is the case, then modulus of elasticity must be same as the slope of the initial tangent of the defined stress-strain curve.

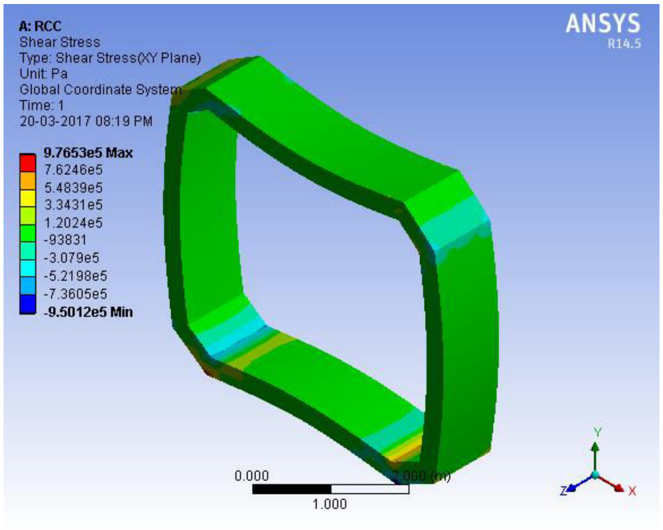


Fig 6.12 Shear Stress in the culvert with haunch

Above Fig shows shear stress on box culvert after analyzing the box culvert under applied loads in ANSYS. We observe that maximum shear stress of 0.976 N/mm^2 is acting at the fixed supports.

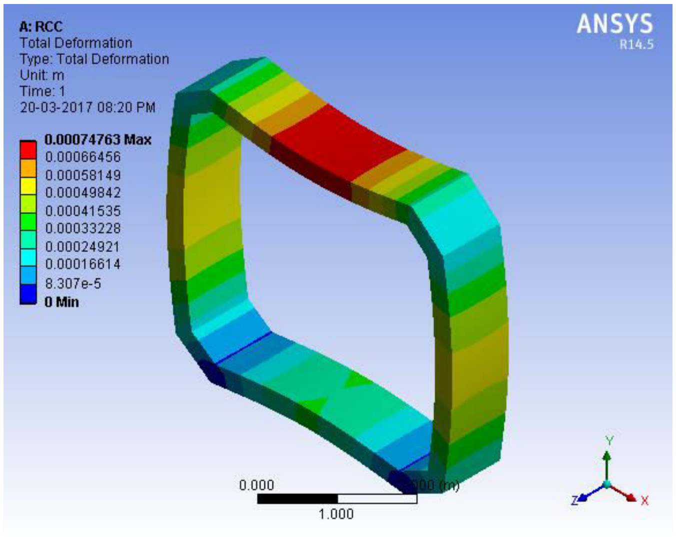


Fig 6.13 Deformation in the culvert with haunch

Above Fig shows deformation on box culvert after analyzing the box culvert under applied loads in ANSYS. We observe that maximum deformation of 0.748 mm is at the middle of top slab. The support conditions also affect the maximum deformations and stress generated in a structure.

6.6 Results from Post - Processing and Observations

Table 36 Comparison of Box Culvert with and without Haunches

Reactions	BC with Haunches	BC without Haunches	Percentage Decrease
Max. Shear Stress (N/mm^2)	0.976	1.027	4.96
Max. Deflection (mm)	0.748	0.956	21.76
Max. Equivalent Stress (N/mm^2)	1.97	3.38	41.7

The outcome of the experiment clearly shows the significant decrease in shear stress, maximum value of deflection and equivalent stress in the culvert by the introduction of haunches into it. The software boundary conditions are kept same for both the cases including the material properties and loading conditions.

Chapter 7

Conclusion

1. From the analysis of Box culverts with varying haunch size it has been observed maximum flexural tensile stresses on top fibre in case of no haunch is 3.029 N/mm^2, for haunch size 0.5 times thickness of wall it is 2.419 N/mm^2, for haunch size 1 times thickness of wall it is 1.851 N/mm^2 for haunch size 1.5 times thickness of wall it is 1.365N/mm^2 and for haunch size 2 times thickness of wall it is 1.0.943 N/mm^2 similarly maximum flexural compressive stresses on top fibre in case of no haunch is 2.801 N/mm^2, for haunch size 0.5 times thickness of wall it is 2.552 N/mm^2, for haunch size 1 times thickness of wall it is 2.260 N/mm^2, for haunch size 1.5 times thickness of wall it is 1.971N/mm^2 and for haunch size 2 times thickness of wall it is 1.693 N/mm^2. From these results it has been observed that there is 68% reduction in tensile stresses of top fibre and 39% reduction in compressive stresses of top fibre.

2. Maximum flexural tensile stresses on bottom fibre in case of no haunch is 1.961 N/mm^2, for haunch size 0.5 times thickness of wall it is 1.711 N/mm^2, for haunch size 1 times thickness of wall it is 1.421 N/mm^2 for haunch size 1.5 times thickness of wall it is 1.129N/mm^2 and for haunch size 2 times thickness of wall it is 1.0.854 N/mm^2 similarly maximum flexural compressive stresses on bottom fibre in case of no haunch is 5.326 N/mm^2, for haunch size 0.5 times thickness of wall it is 4.271 N/mm^2, for haunch size 1 times thickness of wall it is 3.360 N/mm^2 for haunch size 1.5 times thickness of wall it is 2.726N/mm^2 and for haunch size 2 times thickness of wall it is 2.163 N/mm^2. From these results it has been observed that there is 56% reduction in tensile stresses of bottom fibre and 59% reduction in compressive stresses of bottom fibre.

3. From the graphs of X-direction stresses along thickness of wall, obtained from ANSYS results maximum positive bending moment that is span moment is 99.2kNm for box culvert with no haunches, for haunch size 0.5 times thickness of wall it is 88.7kNm, for haunch size 1.0 times thickness of wall it is 76.72kNm, for haunch size 1.5 times thickness of wall it is 64.16kNm and for haunch size 2.0 times thickness of wall it is 53.03kNm.

4. From the graphs of X-direction stresses along thickness of wall, obtained from ANSYS results maximum negative bending moment that is end moment is 174.06kNm for box culvert with no haunches, for haunch size 0.5 times thickness of wall it is 139.23kNm, for haunch size 1.0 times thickness of wall it is 106.27kNm, for haunch size 1.5 times thickness of wall it is 82.24kNm and for haunch size 2.0 times thickness of wall it is 69.11kNm.

5. From Table No.35 it is found that volume of concrete required for box culvert with no haunch is 92.4m^3 and this quantity required reduces to 74.5m^3 for haunch size of 1.5 times thickness of wall. Volume of concrete required for box culvert with haunch size 0.5 times thickness of wall is 84.0m^3, for box culvert with haunch size 1.0 times thickness of wall is 77.5m^3, for box culvert with haunch size 2.0 times thickness of wall is 75.5m^3,

6. After design of box culvert with the help of above results by conventional working stress method it have been observed that there is reduction in concrete volume of 18.0 m^3 i.e. 19.37% for haunch size 2 times thickness of wall and 18.35% for haunch size 1.5 times thickness of wall and reduction in reinforcement for negative bending moment is 30%, however it is found that there is not any significant change in reinforcement required for positive bending moment.

7. It is found from Table No.35 that quantity of steel required for box culvert with no haunches is 953.7 quintal and this quantity reduces to 741 quintal when haunch size increases to 2.0 times thickness of wall and therefore .combined cost of concrete and steel reduces from 52,30,500 rupees to 40,82,500 rupees i.e. decreases by 11,48,000 rupees.

8. It is found from Table No. 36 that introduction of haunch to a box culvert significantly decreases the stresses and deformation. In given experimental study, shear stress is reduced by 4.96%, maximum deflection reduced by 21.76% and equivalent stress is decreased by 41.7% which is a huge difference.

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