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Structural Analysis of Three-Cell Box Culverts: A Study Considering Different S/H Ratios with Diverse Skew Angles

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Abstract: A crucial role is played by box culverts as vital structures, having been constructed in diverse forms and dimensions to meet a range of waterway and traffic requirements.
A pathway beneath roads is offered, ensuring safe traversal without road traffic disruption, thus providing users with a secure journey. Typically, box culverts are utilized for this purpose. A variety of pressures from water, traffic, cushion, and soil are endured by these structures.
In this paper to check the box culvert against various loads and alignment, 3 box cell culvert with 12 distinct cases have taken A2 to L2 having 4 sets of models of different S/H ratios 1.5, 1.75 and 2. In each sets, 4 combinations have taken of different skew angles viz. 0, 17, 34 and 51 degree respectively. After then these all 12 models have checked and efficient model under head of each degree and S/H noted. Finally, the result concluded that use skewness up to 17 degree with more S/H ratio to create an economic 3 cell box culvert.
Keywords: Displacements, Box Culvert, 3 Cell Box, 70R loading, Stresses, H/S ratio, Skew angles, Support Reactions.

I. INTRODUCTION

Box culverts play a crucial role in ensuring proper water discharge, particularly in situations such as railway crossings, flyovers, and roads, where the soil's bearing capacity is limited.
They present a cost-effective alternative to bridges, especially in terms of when roadway crosses a high embankment or when discharge in the opening. While box culverts are typically constructed in place in India, other countries tend to favour them due to their affordability, economic efficiency, and swift construction. The term "box" denotes its shape, which varies based on specific requirements.
The culvert's height corresponds to its span, enabling effective management of various water sources, including irrigation, surface water, rivers, and canals. This culvert design adeptly handles storm water and floodwater during the rainy season.

II. SKEWNESS OF 3 CELL BOX CULVERT

The angular deviation from a perpendicular alignment to the roadway or watercourse span is referred to as the skewness of a three cell box culvert.
When a pair of box culverts is considered, the design and functionality are influenced by skewness as a critical factor. Challenges in hydraulic efficiency, structural stability, and overall performance are introduced by a higher degree of skewness. The skew angle significantly affects the geometry and flow dynamics of the culvert, potentially resulting in uneven water distribution, increased turbulence, and altered sediment transport patterns.
The implications of skewness in dual box culverts must be carefully assessed and addressed by engineers to ensure optimal water conveyance, structural integrity, and long-term functionality.

Factors that are used to provide different ranges of skewness provided in box culvert are:-

1) Hydraulic Considerations
2) Traffic Considerations
3) Structural Considerations

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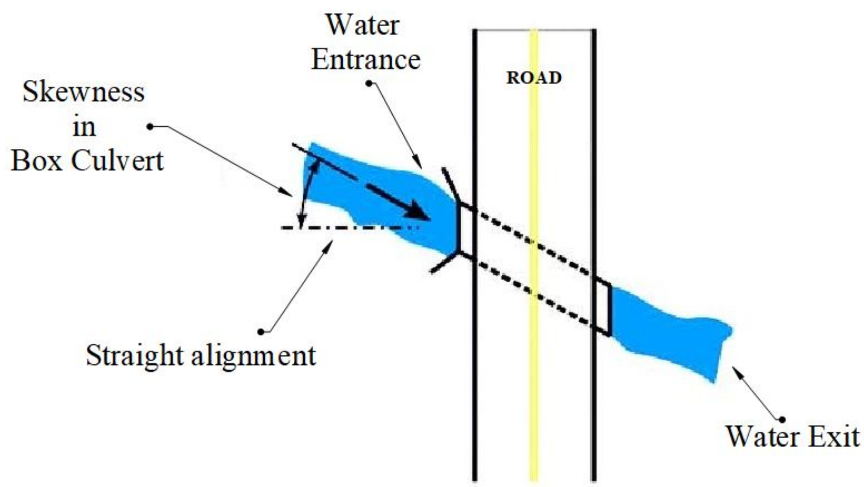

Fig. 1: A general idea on skewness provided in box culvert

III. PROCEDURE AND 3D MODELLING OF THE STRUCTURE

Comprehensive input data and its descriptions about the model given below. This input data for 3 cell box culvert will be essential to create accurate models that ultimately gives better results under the guidance of IRC 6: 2000.

Table 1: Input details for 3 Cell Box culvert

Concrete grade	M30
Rebar grade	415
Top slab thickness	0.45 m
Bottom slab thickness	0.45 m
Side wall thickness	0.45 m
Unit weight of concrete	30 KN/ cu. M.
Unit weight of soil	20 KN/ cu. M.
Modulus of subgrade reaction	300000 KN/ cu. M./ m.
Coefficient of earth pressure C	0.33
Number of plate meshing	10 x 10
Skew angle used	0, 17, 34 and 51 degrees
Road width	7.5 m (for 2 lane road)
Span of each cell	3m
Height of cell	For S/H of 1.5m = 4m height For S/H of 1.75m = 3.42m height For S/H of 2m = 3m height
IRC loading used	70R
Dead load	Self-Weight
Surcharge load of soil on both the sides	= 2 x 20 x 0.33 = 13.2 KN/ sq. m. = 6.6 KN/ sq. m. on each side

Table 2: Model Description

Models framed for analysis	Abbreviation
3 cell box culvert (H to S = 1.5) (0 degree)	A2
3 cell box culvert (H to S = 1.5) (17 degree)	B2
3 cell box culvert (H to S = 1.5) (34 degree)	C2
3 cell box culvert (H to S = 1.5) (51 degree)	D2
3 cell box culvert (H to S = 1.75) (0 degree)	E2
3 cell box culvert (H to S = 1.75) (17 degree)	F2
3 cell box culvert (H to S = 1.75) (34 degree)	G2
3 cell box culvert (H to S = 1.75) (51 degree)	H2
3 cell box culvert (H to S = 2) (0 degree)	I2
3 cell box culvert (H to S = 2) (17 degree)	J2
3 cell box culvert (H to S = 2) (34 degree)	K2
3 cell box culvert (H to S = 2) (51 degree)	L2

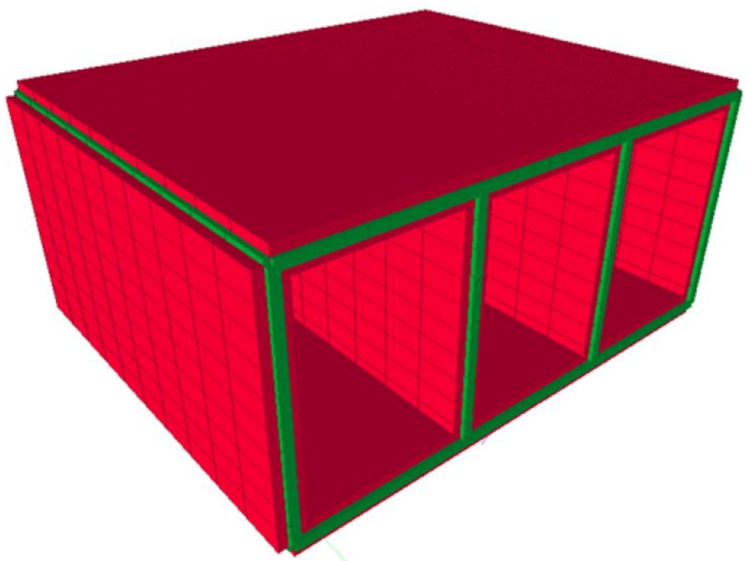

Fig. 2: 3D View of 3 cell Box culvert

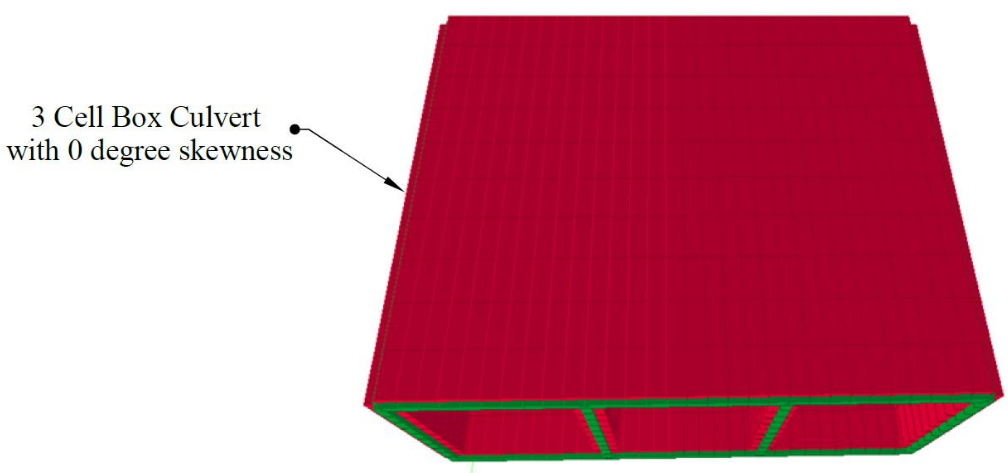

Fig. 3: 3 cell Box culvert (0 degree)

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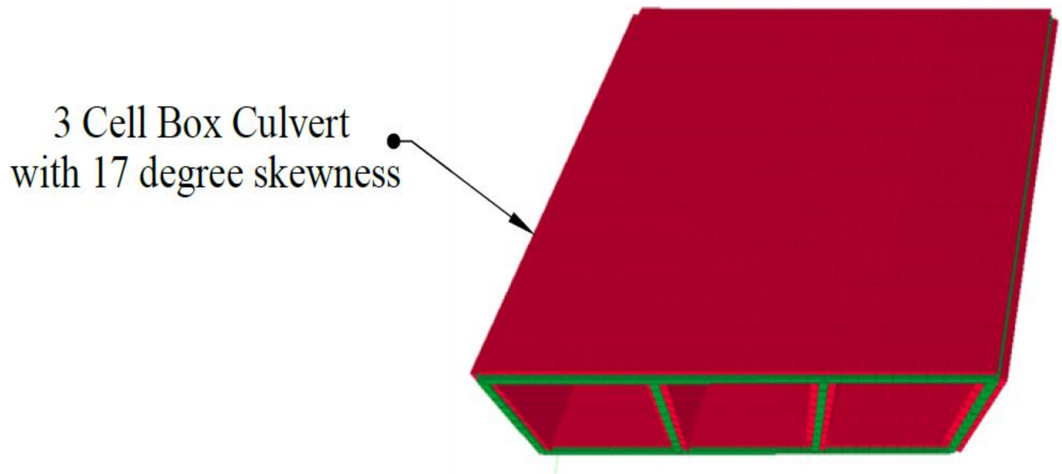

Fig. 4: 3 cell Box culvert (17 degree)

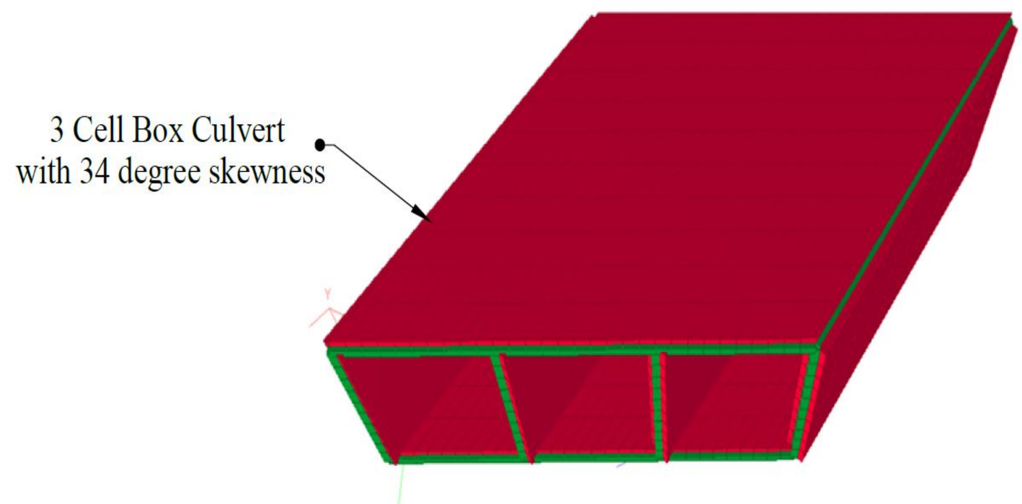

Fig. 5: 3 cell Box culvert (34 degree)

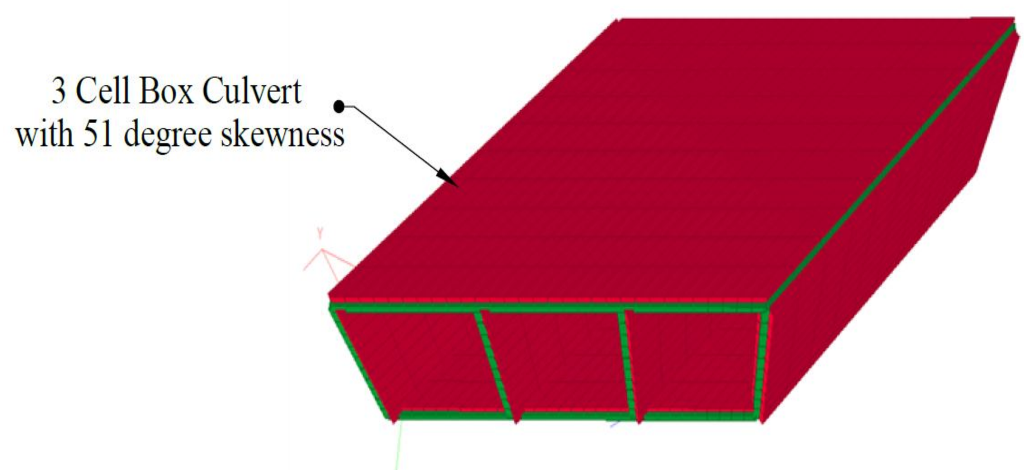

Fig. 6: 3 cell Box culvert (51 degree)

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IV. RESEARCH OBJECTIVES

On keeping in mind the above problem statement outlined for new research work for box culvert are given below :-

1) To check behavior in the analysis, it is recommended to take different skew angles like 0 degree, 17 degree, 34 degree and 51 degree. This analysis should be check with different S/H ratio like 1.5, 1.75 and 2.
2) For accuracy in analysis, it is essential to create and study 12 distinct cases involving various cases from 3 cell box culvert (A2 to L2).
3) To determine and compare maximum displacement in X, Y and Z direction for all the skew cases for different S/H ratios.
4) To study the variation in maximum support reactions and find out the efficient case among 12 cases (A2 to L2) for 3 cell box culverts.
5) To determine and relate the maximum shear forces and bending moment in plate members (slab and wall member) beam member and find out the efficient case among 12 cases (A2 to L2) for 3 cell box culverts.
6) To evaluate maximum stresses like Principal Stresses, Equivalent Stresses and Maximum Shear Stresses in plate members (slab and wall member) beam member and find out the efficient case among 12 cases (A2 to L2) for 3 cell box culverts.
7) To compare different parametric values and mark the economic one for 3 box and at last, provide the recommendations that will made a feasible construction reference.

V. RESULTS ANALYSIS

The application of loads on different cases with various skewness configurations yield result parameters:-

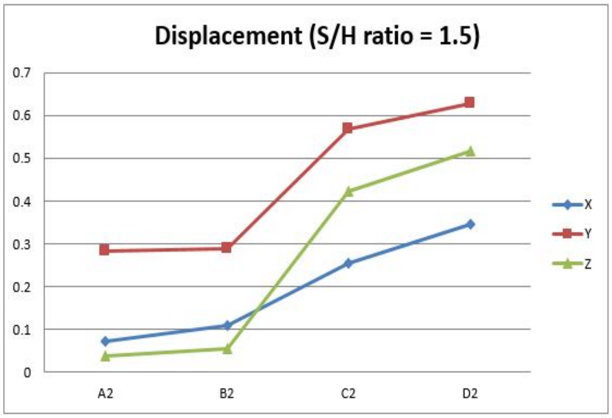

Fig. 7: Maximum Displacement for 3 cell box culvert (S/H ratio = 1.5)

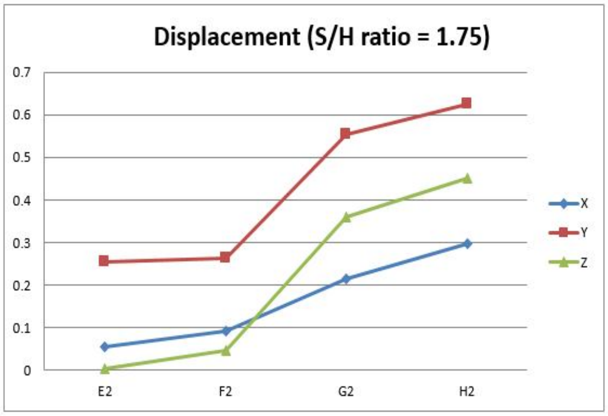

Fig. 8: Maximum Displacement for 3 cell box culvert (S/H ratio = 1.75)

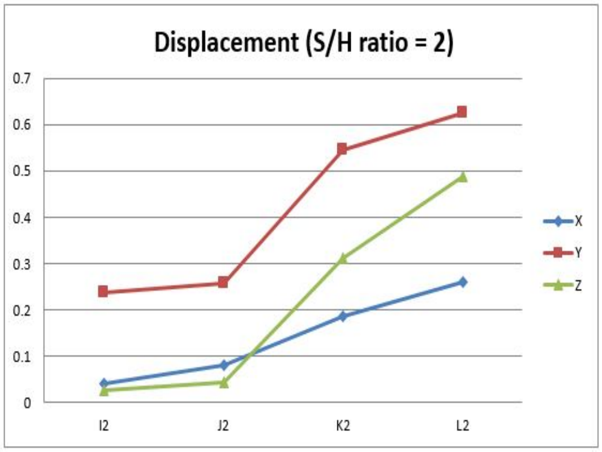

Fig. 9: Maximum Displacement for 3 cell box culvert (S/H ratio = 2)

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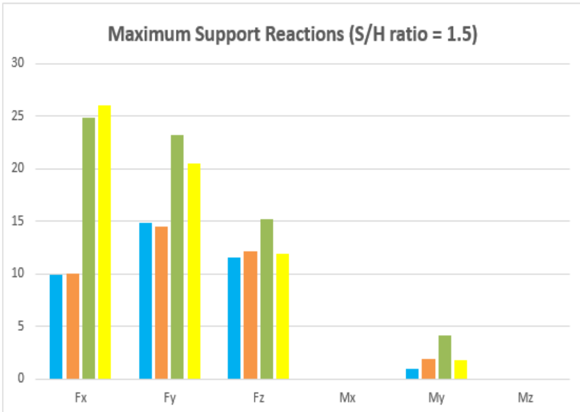

Fig. 10: Maximum Support Reactions for 3 cell box culvert (S/H ratio = 1.5)

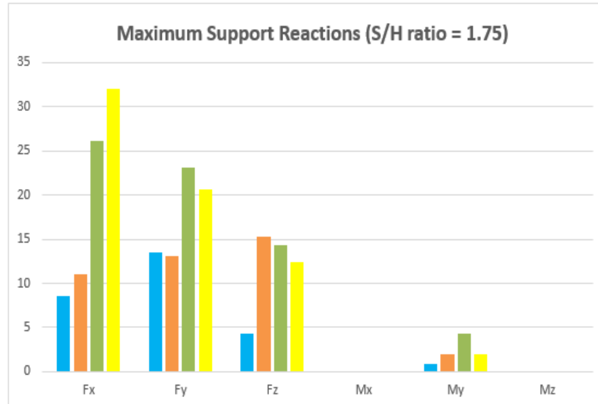

Fig. 11: Maximum Support Reactions for 3 cell box culvert (S/H ratio = 1.75)

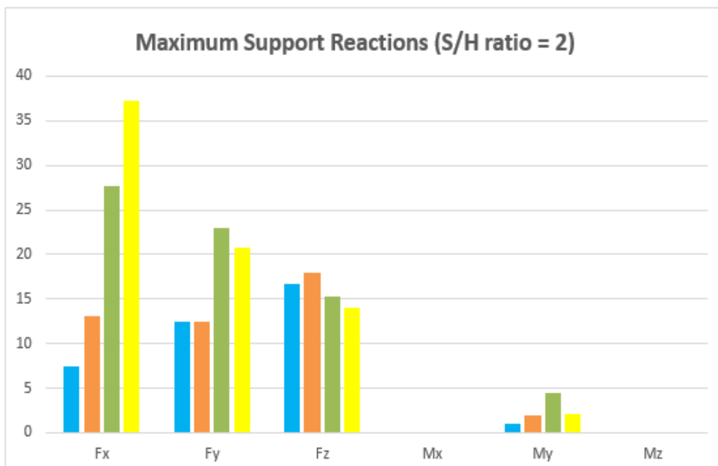

Fig. 12: Maximum Support Reactions for 3 cell box culvert (S/H ratio = 2)

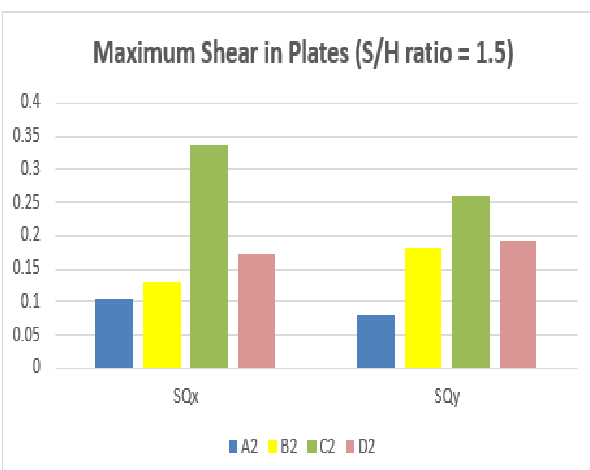

Fig. 13: Maximum Shear in Plates for 3 cell box culvert (S/H ratio = 1.5)

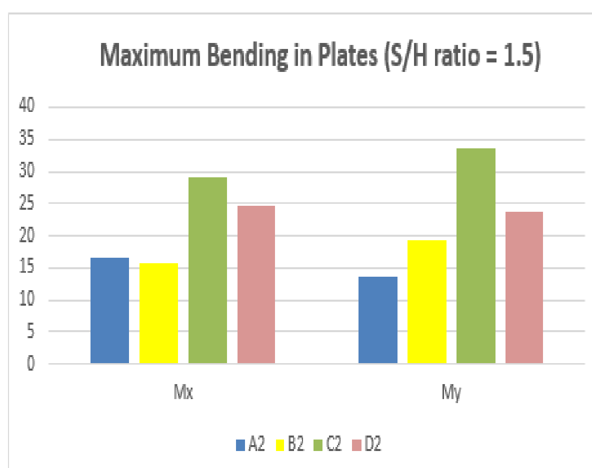

Fig. 14: Maximum Bending in Plates for 3 cell box culvert (S/H ratio = 1.5)

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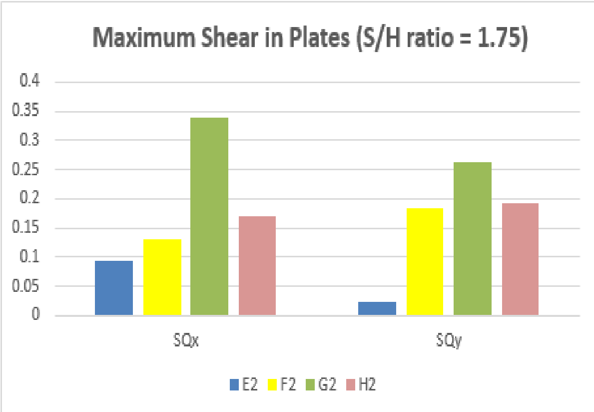

Fig. 15: Maximum Shear in Plates for 3 cell box culvert (S/H ratio = 1.75)

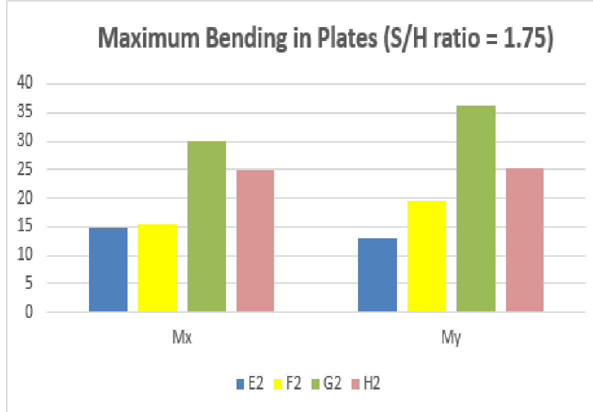

Fig. 16: Maximum Bending in Plates for 3 cell box culvert (S/H ratio = 1.75)

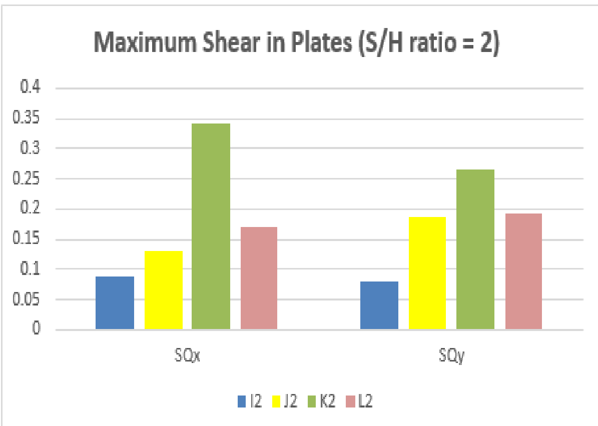

Fig. 17: Maximum Shear in Plates for 3 cell box culvert (S/H ratio = 2)

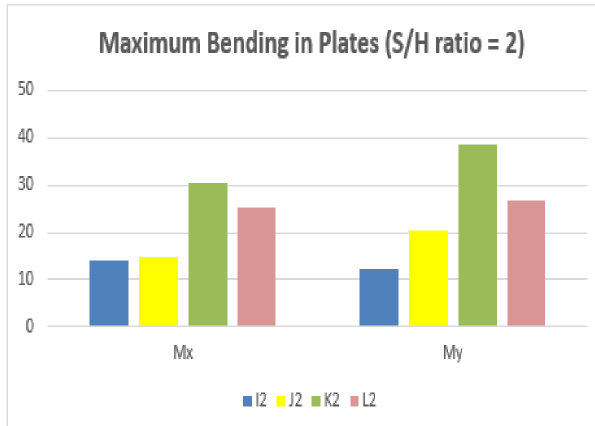

Fig. 18: Maximum Bending in Plates for 3 cell box culvert (S/H ratio = 2)

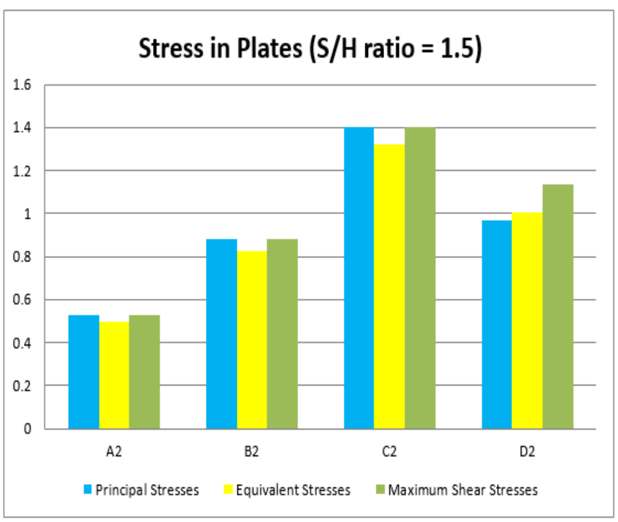

Fig. 19: Maximum Stress in Plates for 3 cell box culvert (S/H ratio = 1.5)

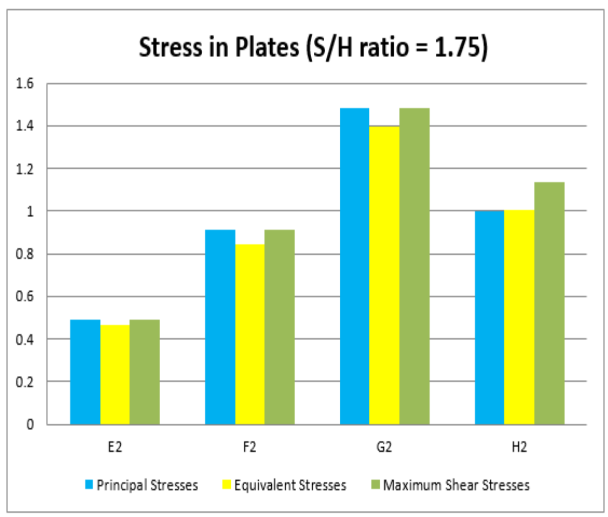

Fig. 20: Maximum Stress in Plates for 3 cell box culvert (S/H ratio = 1.75)

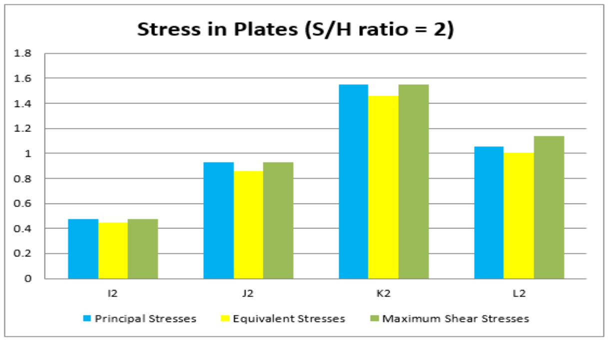

Fig. 21: Maximum Stress in Plates for 3 cell box culvert (S/H ratio = 2)

VI. CONCLUSIONS

The conclusion can be pointed out for 3 cell box culvert are as follows:-

A. *Comparison with 0 Degree*

1) On comparing 0 degree, with increase in ratio, displacement decreases in X, Y and Z direction
2) On comparing 0 degree, with increase in ratio, the support reaction values in Fx decreases, Fy decreases, Fz and My first decreases then increases.
3) On comparing 0 degree, with increase in ratio, the shear forces SQx in plates decreases, SQy in plates first decreases then increases, moment Mx in plates decreases and moment My in plates decreases.
4) On comparing 0 degree, with increase in ratio, the principal stresses in plates decreases, equivalent stresses in plates decreases and shearing stresses decreases.

B. *Comparison with 17 Degree*

1) On comparing 17 degree, with increase in ratio, displacement decreases in X, Y and Z direction
2) On comparing 17 degree, with increase in ratio, the support reaction values in Fx increases, Fy decreases, Fz increases and My increases.
3) On comparing 17 degree, with increase in ratio, the shear forces SQx in plates increases, SQy in plates increases, moment Mx in plates decreases and moment My in plates increases.
4) On comparing 17 degree, with increase in ratio, the principal stresses in plates increases, equivalent stresses in plates increases and shearing stresses increases.

C. *Comparison with 34 Degree*

1) On comparing 34 degree, with increase in ratio, displacement decreases in X, Y and Z direction
2) On comparing 34 degree, with increase in ratio, the support reaction values in Fx increases, Fy decreases, Fz first decreases then increases and My increases.
3) On comparing 34 degree, with increase in ratio, the shear forces SQx in plates increases, SQy in plates increases, moment Mx in plates increases and moment My in plates increases.
4) On comparing 34 degree, with increase in ratio, the principal stresses in plates increases, equivalent stresses in plates increases and shearing stresses increases.

D. *Comparison with 51 Degree*

1) On comparing 51 degree, with increase in ratio, displacement decreases in X, Y and Z direction.
2) On comparing 51 degree, with increase in ratio, the support reaction values in Fx increases, Fy increases, Fz increases and My increases.
3) On comparing 51 degree, with increase in ratio, the shear forces SQx in plates decreases, SQy in plates increases, moment Mx in plates increases and moment My in plates increases.
4) On comparing 51 degree, with increase in ratio, the principal stresses in plates increases, equivalent stresses and shearing stresses in plates first increases then decreases.

E. Comparison with S/H ratios

1) For S/H ratio = 1.5

a) On comparing displacement values, maximum values observed in case D2 only for X, Y and Z direction having value of S/H ratio = 1.5 respectively.

b) On comparing maximum support reactions values, as the S/H ratio is fixed to 1.5, the structure increases the forces observations. Values of Fx, Fy and Fz also increases. Observing moment values, Mx and Mz observed null values, hence not considered. My has maximum value of 4.210 KNm (C2) respectively.

c) Observing shear and bending in plates, case C2 has observed maximum values when comparing cases from A2 to D2 respectively when S/H ratio is fixed for 1.5.

d) Comparing all 3 stresses in plates, case C2 observed as critical case comparing when S/H ratio is fixed for 1.5.

2) For S/H ratio = 1.75

a) On comparing displacement values, maximum values observed in case H2 only for X, Y and Z direction having value of S/H ratio = 1.75 respectively.

b) On comparing maximum support reactions values, as the S/H ratio is fixed to 1.75, the structure increases the forces observations. Values of Fx, Fy and Fz also increases. Observing moment values, Mx and Mz observed null values, hence not considered. My has maximum value of 4.371 KNm (G2) respectively.

c) Observing shear and bending in plates, case G2 has observed maximum values when comparing cases from E2 to H2 respectively when S/H ratio is fixed for 1.75.

d) Comparing all 3 stresses in plates, case G2 observed as critical case comparing when S/H ratio is fixed for 1.75.

3) For S/H ratio = 1.2

a) On comparing displacement values, maximum values observed in case L2 only for X, Y and Z direction having value of S/H ratio = 2 respectively.

b) On comparing maximum support reactions values, as the S/H ratio is fixed to 2, the structure increases the forces observations. Values of Fx, Fy and Fz also increases. Observing moment values, Mx and Mz observed null values, hence not considered. My has maximum value of 4.521 KNm (K2) respectively.

c) Observing shear and bending in plates, case K2 has observed maximum values when comparing cases from I2 to L2 respectively when S/H ratio is fixed for 2.

d) Comparing all 3 stresses in plates, case K2 observed as critical case comparing when S/H ratio is fixed for 2.

This project concluded that when comparing all the result parameters, for 3 cell box culvert, in most of the cases, 34 degree and 51 degree are more critical as compared to 17 degree and most favorable degree is 0 degree. Hence should be recommended when this type of construction procedure adopted, i.e. always use skewness upto 17 degree with more S/H ratio.

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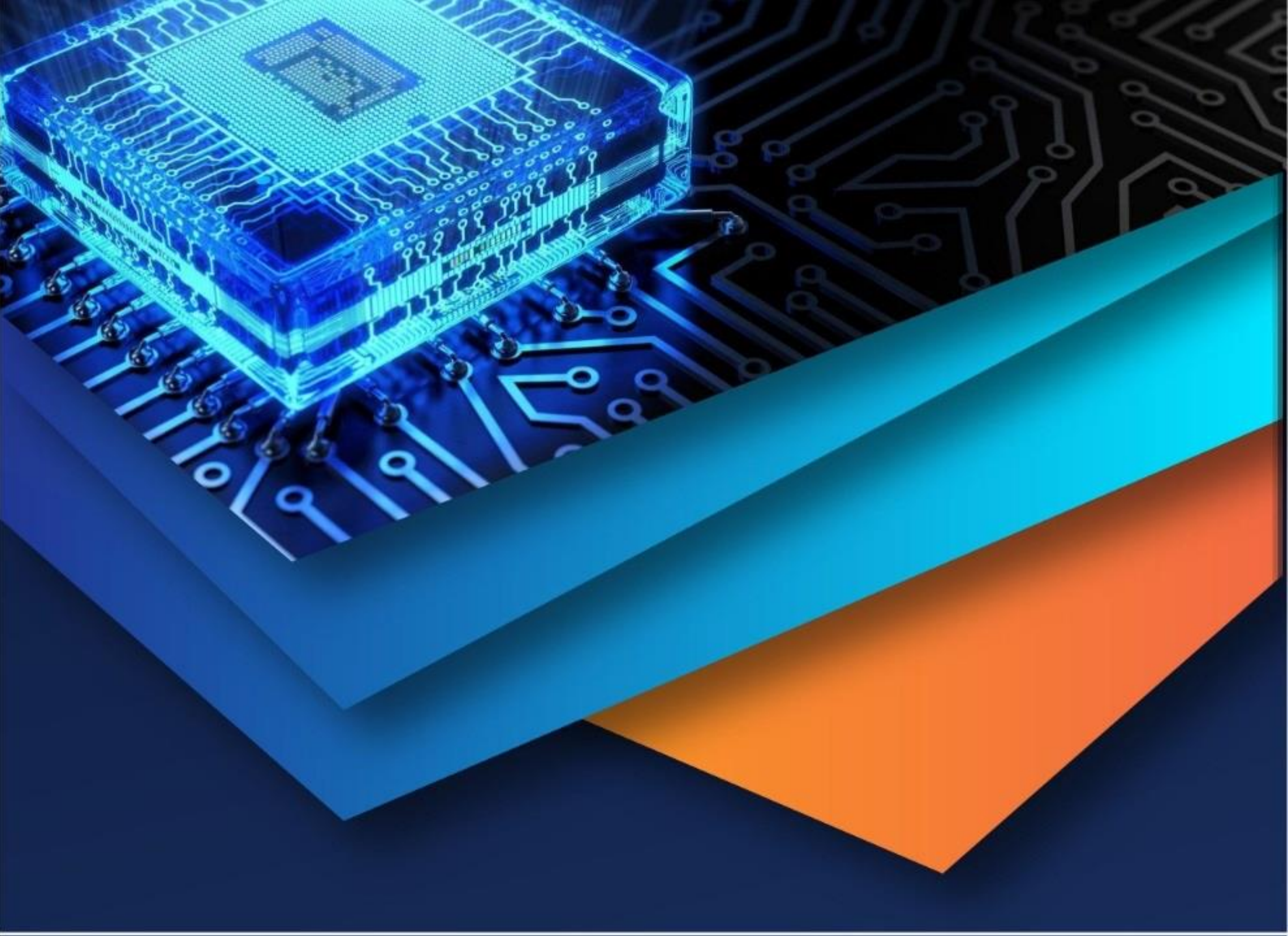

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