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

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Abstract: ***Box culverts play a crucial role as vital structures, having been built in diverse forms and dimensions to provide a range of waterway and traffic requirements. They offer a pathway beneath roads, ensuring safe traversal without disrupting road traffic, thus affording users a secure journey. Typically, box culverts are employed for this purpose. These structures endure a variety of pressures from water, traffic, cushion and soil. In this paper to check the box culvert against various loads and alignment, 2 box cell culvert with 12 distinct cases have taken A1 to L1 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 2 cell box culvert.***
Keywords: ***Box Culvert, 70R loading, H/S ratio, Skew angles, 2 Cell Box, Displacements, Stresses.***

I. INTRODUCTION

Box culverts serve as essential structures for discharging water properly, especially in crossings of railways, flyovers, and roads, where soil bearing capacity is low. They offer an economical solution compared to bridges, particularly in terms of discharge in the opening or when roadway crosses a high embankment. In India, box culverts are generally cast in situ, but in other countries, they are preferred due to their low cost, economic efficiency, and fast construction. The term "box" refers to its shape, and it comes in various shapes depending on the specific needs. Their height is determined by the span, and they effectively control all types of water, including irrigation, surface water, rivers, and canals, efficiently managing storm water and floodwater during the rainy season.

II. SKEWNESS OF 2 BOX CULVERT

The skewness of a dual box culvert refers to the angular deviation from a perpendicular alignment to the roadway or watercourse it spans. When considering a pair of box culverts, skewness becomes a critical factor influencing their design and functionality.

A higher degree of skewness introduces challenges in hydraulic efficiency, structural stability, and overall performance. The geometry and flow dynamics of the culvert are notably affected by the skew angle, potentially leading to uneven water distribution, increased turbulence, and altered sediment transport patterns. Engineers must carefully assess and address the implications of skewness in dual box culverts 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

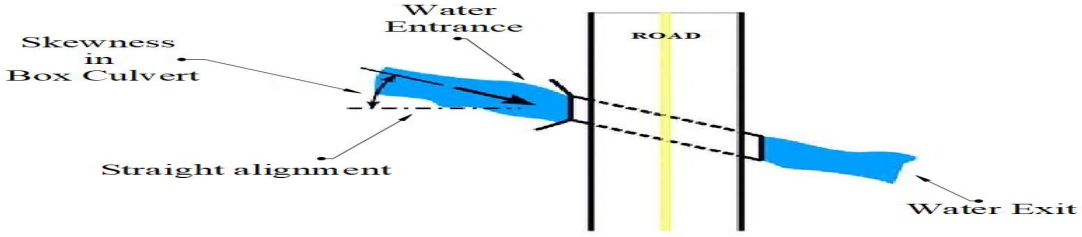

Fig. 1: A general idea on skewness provided in box culvert

III. PROCEDURE AND 3D MODELLING OF THE STRUCTURE

Comprehensive input data and its descriptions about the model given below. This input data for 2 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 2 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	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
2 cell box culvert (H to S = 1.5) (0 degree)	A1
2 cell box culvert (H to S = 1.5) (17 degree)	B1
2 cell box culvert (H to S = 1.5) (34 degree)	C1
2 cell box culvert (H to S = 1.5) (51 degree)	D1
2 cell box culvert (H to S = 1.75) (0 degree)	E1
2 cell box culvert (H to S = 1.75) (17 degree)	F1
2 cell box culvert (H to S = 1.75) (34 degree)	G1
2 cell box culvert (H to S = 1.75) (51 degree)	H1
2 cell box culvert (H to S = 2) (0 degree)	I1
2 cell box culvert (H to S = 2) (17 degree)	J1
2 cell box culvert (H to S = 2) (34 degree)	K1
2 cell box culvert (H to S = 2) (51 degree)	L1

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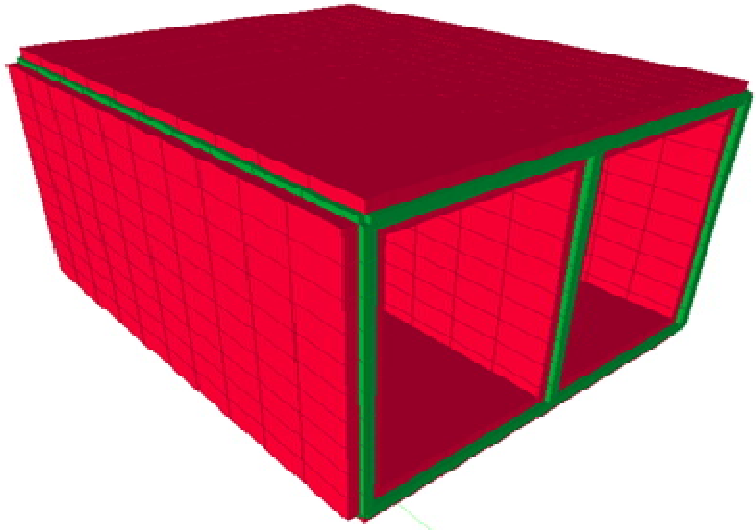

Fig. 2: 3D View of 2 cell Box culvert

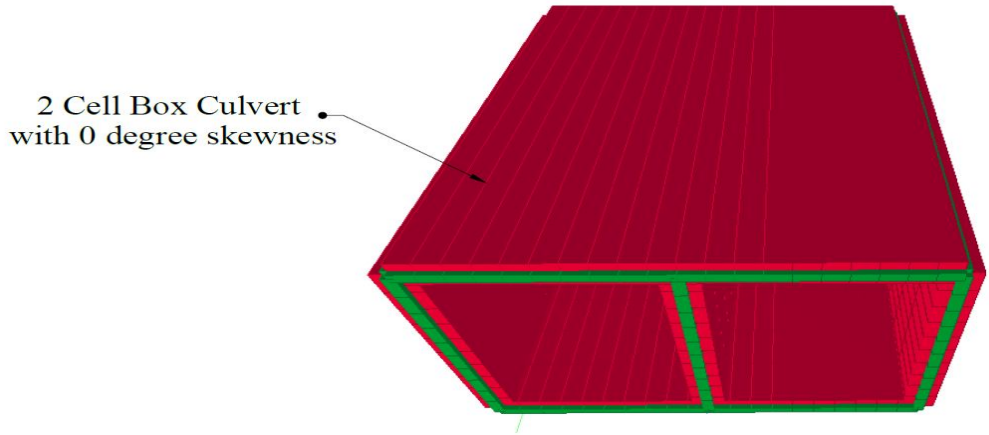

Fig. 3: 2 cell Box culvert (0 degree)

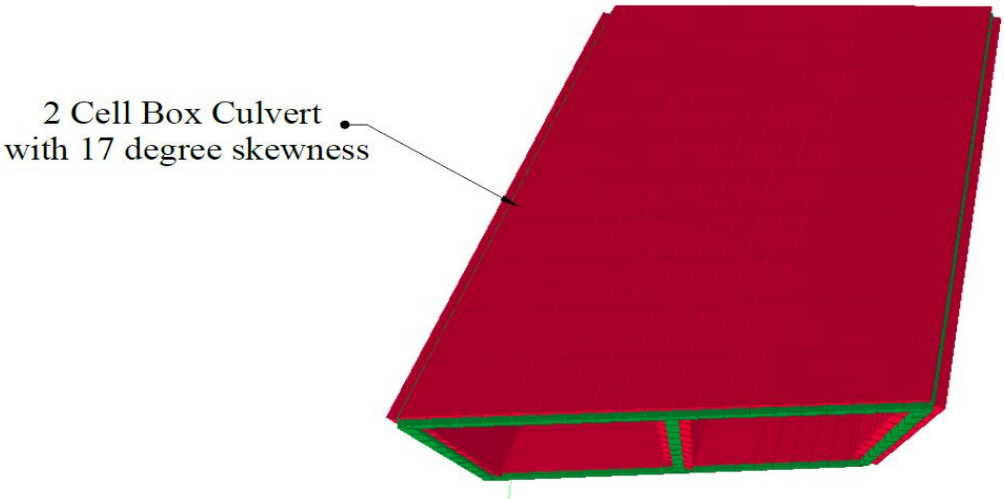

Fig. 4: 2 cell Box culvert (17 degree)

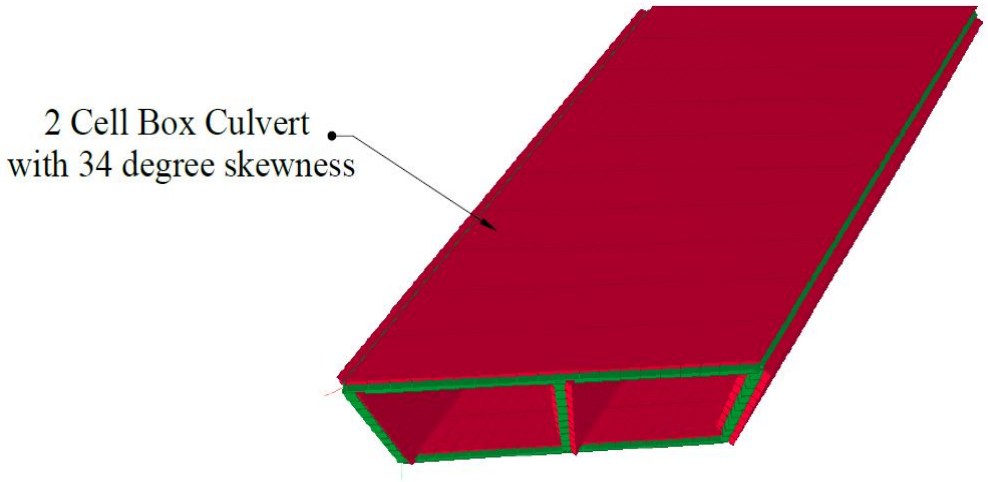

Fig. 5: 2 cell Box culvert (34 degree)

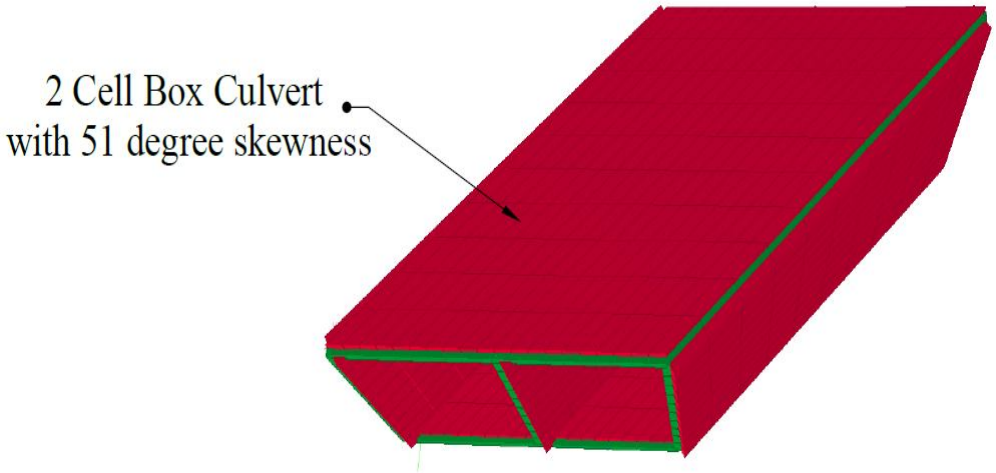

Fig. 6: 2 cell Box culvert (51 degree)

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 2 cell box culvert (A1 to L1).
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 (A1 to L1) for 2 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 (A1 to L1) for 2 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 (A1 to L1) for 2 cell box culverts.
7) To compare different parametric values and mark the economic one for 2 box and at last, provide the recommendations that will made a feasible construction reference.

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V. RESULTS ANALYSIS

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

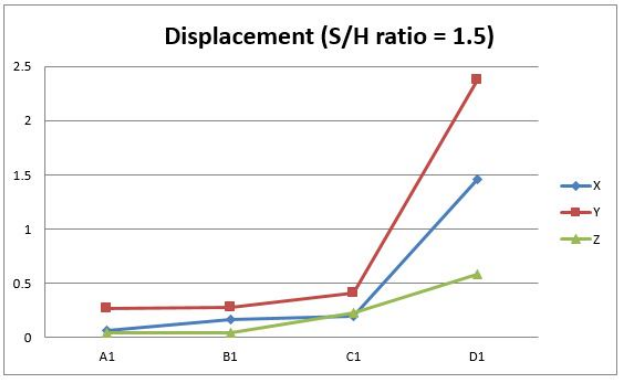

Fig. 7: Maximum Displacement for 2 cell box culvert (S/H ratio = 1.5)

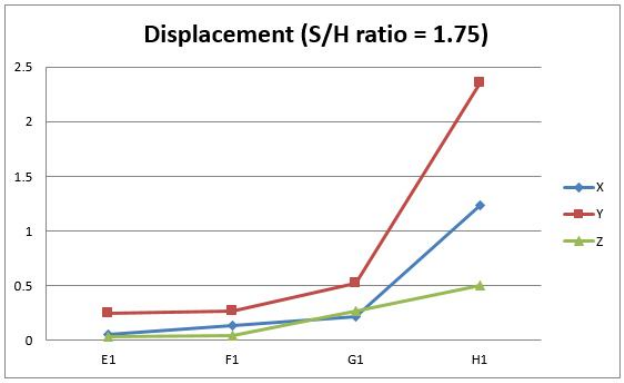

Fig. 8: Maximum Displacement for 2 cell box culvert (S/H ratio = 1.75)

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

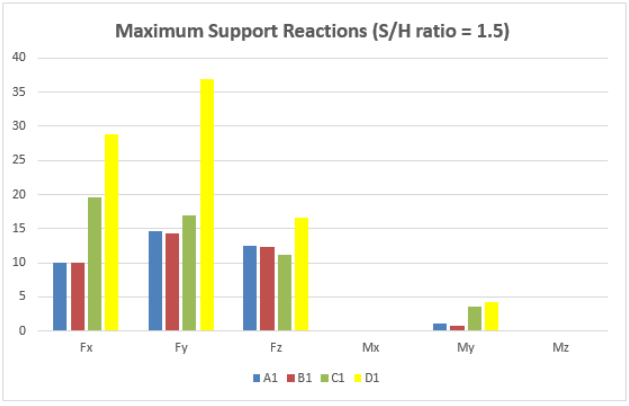

Fig. 10: Maximum Support Reactions for 2 cell box culvert (S/H ratio = 1.5)

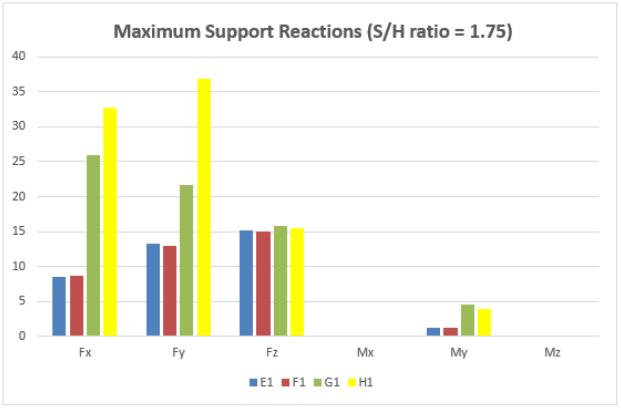

Fig. 11: Maximum Support Reactions for 2 cell box culvert (S/H ratio = 1.75)

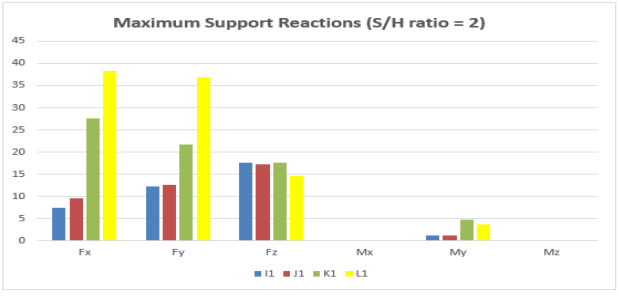

Fig. 12: Maximum Support Reactions for 2 cell box culvert (S/H ratio = 2)

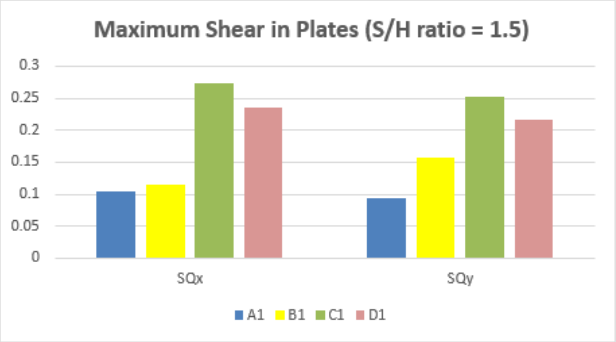

Fig. 13: Maximum Shear in Plates for 2 cell box culvert (S/H ratio = 1.5)

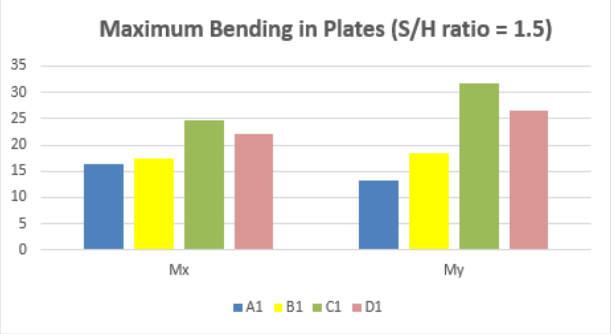

Fig. 14: Maximum Bending in Plates for 2 cell box culvert (S/H ratio = 1.5)

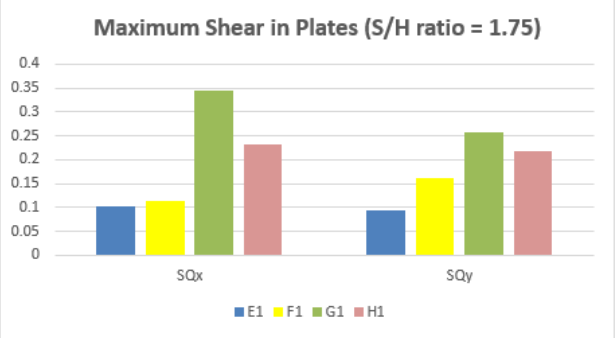

Fig. 15: Maximum Shear in Plates for 2 cell box culvert (S/H ratio = 1.75)

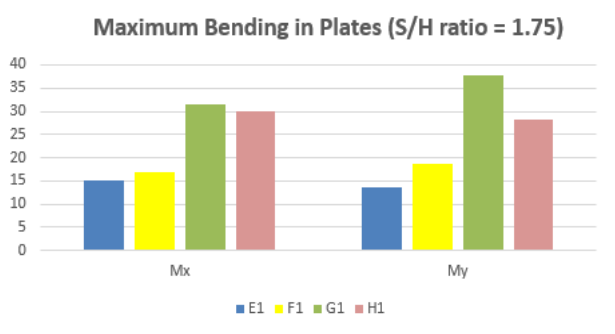

Fig. 16: Maximum Bending in Plates for 2 cell box culvert (S/H ratio = 1.75)

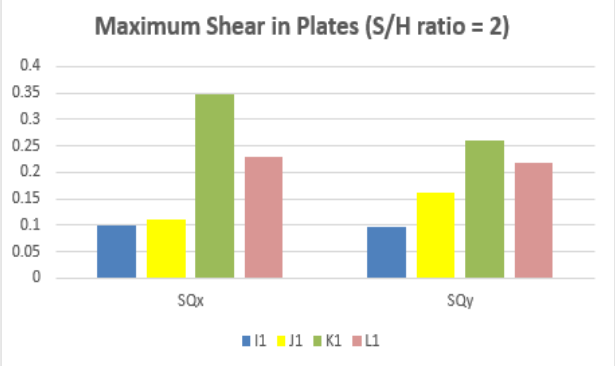

Fig. 17: Maximum Shear in Plates for 2 cell box culvert (S/H ratio = 2)

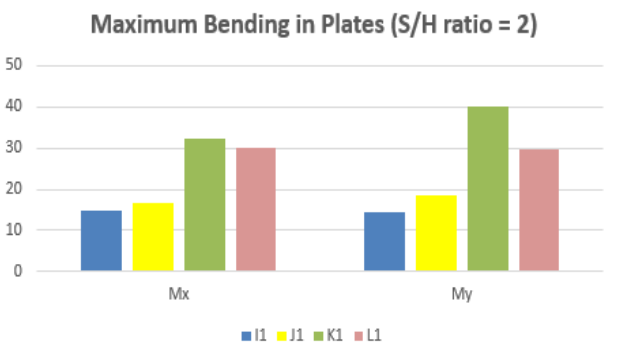

Fig. 18: Maximum Bending in Plates for 2 cell box culvert (S/H ratio = 2)

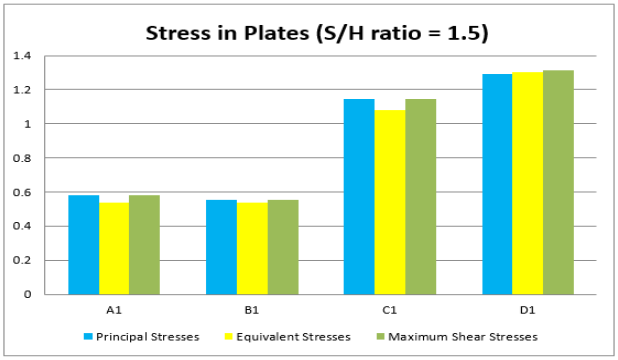

Fig. 19: Maximum Stress in Plates for 2 cell box culvert (S/H ratio = 1.5)

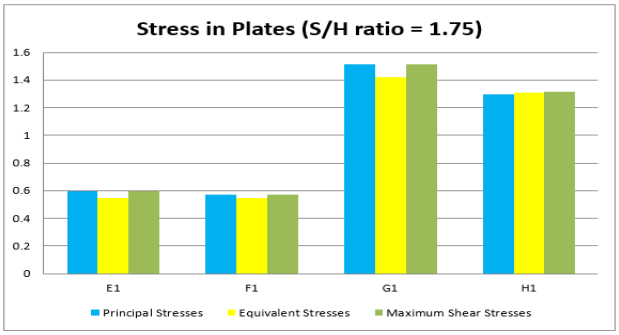

Fig. 20: Maximum Stress in Plates for 2 cell box culvert (S/H ratio = 1.75)

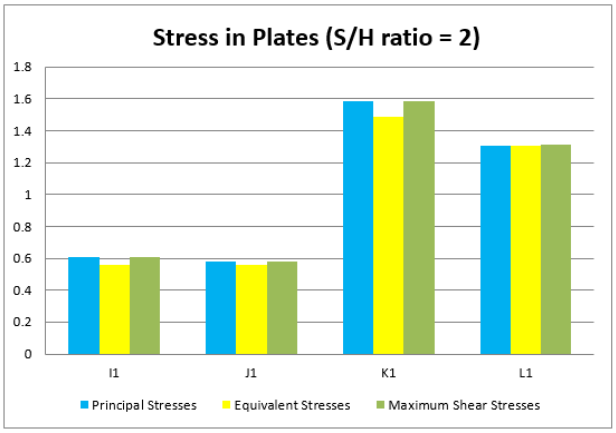

Fig. 21: Maximum Stress in Plates for 2 cell box culvert (S/H ratio = 2)

VI. CONCLUSIONS

The conclusion can be pointed out for 2 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 increases and My increases.

3) On comparing 0 degree, with increase in ratio, the shear forces SQx in plates decreases, SQy in plates increases, moment Mx in plates decreases and moment My in plates increases.

4) On comparing 0 degree, with increase in ratio, the principal stressesin plates increases, equivalent stresses in plates increases and shearing stresses increases.

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 decreases, Fy decreases, Fz increases and My increases.

3) On comparing 17 degree, with increase in ratio, the shear forces SQx in plates decreases, 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 first increases then decreases in X, Y and Z direction

2) On comparing 34 degree, with increase in ratio,the support reaction values in Fx increases, Fy first increases then decreases, Fz 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, Fzdecreases 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 in plates increases and shearing stresses increases.

E. Comparison with S/H ratios

1) For S/H ratio = 1.5

a) On comparing displacement values, maximum values observed in case D1 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 4.178 KNm (D1) respectively.

c) Observing shear and bending in plates, case C1 has observed maximum values when comparing cases from A1 to D1 respectively when S/H ratio is fixed for 1.5.

d) Comparing all 3 stresses in plates, case D1 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 H1 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 4.512 KNm (G1) respectively.

c) Observing shear and bending in plates, case G1 has observed maximum values when comparing cases from E1 to H1 respectively when S/H ratio is fixed for 1.75.

d) Comparing all 3 stresses in plates, case G1 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 L1 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 4.681 KNm (K1) respectively.

c) Observing shear and bending in plates, case K1 has observed maximum values when comparing cases from I1 to L1 respectively when S/H ratio is fixed for 2.

d) Comparing all 3 stresses in plates, case K1 observed as critical case comparing when S/H ratio is fixed for 2.

This project concluded that when comparing all the result parameters, for 2 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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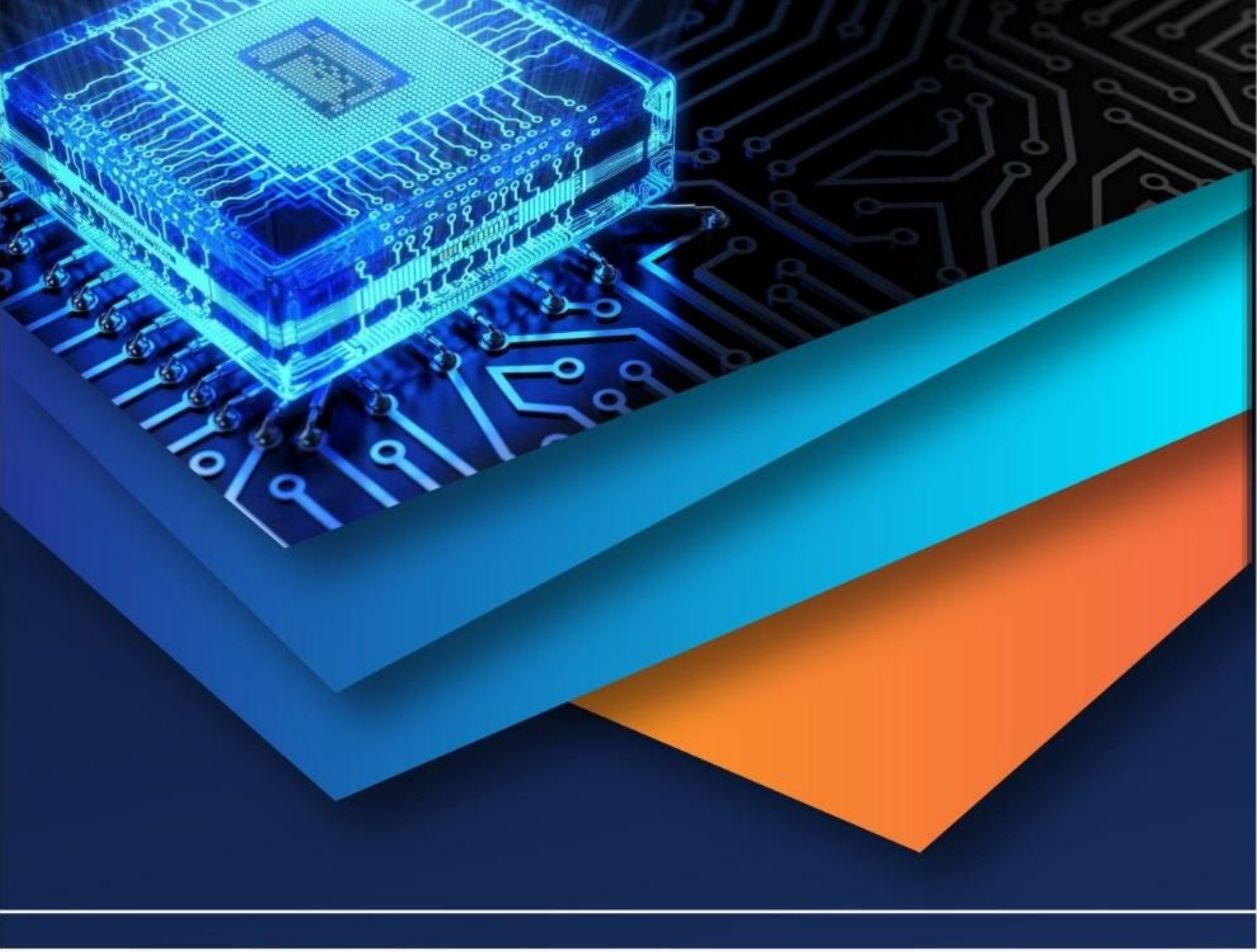

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