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Effect of Skew Angle on the Behavior of Bowstring Girder Bridge

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Abstract - *The presence of Skew angle in the bridge plays an important role. All the times it is not possible to have 0 degree skew bridge or straight bridge, therefore at certain situations it is necessary to provide certain amount of skew to the bridge. In such situations special attention required to understand the behavior of bridge. The stresses distribution in the bridge is not uniform and it varies with the skew angle. Few studies shows that up to 20 degree skew angle the behavior of the bridge is similar to the straight bridge, but beyond 20 degree the behavior is quite different.*

This project concentrates on effect of skew angle on the behaviour of bowstring Girder Bridge. Four models were developed for 4 different skew angles and skew angles are 0, 30, 45 and 60 degree. The 3D model of the bridge have been created by using finite element based software SAP2000. The bridge is subjected to self-weight, footway load, IRC Class A, IRC Class 70R, IRC Class AA Tracked and Special vehicle loading as per IRC 6-2014. The predominant axial force, bending moment and shear forces in the members are noted. The variation of support reactions with the variation of skew angles also included. Finally the behaviour of the bridge for different skew angles is compared by plotting the graphs.

Key Words: **Skew Angle, Bowstring Girder Bridge, Predominant Axial Force, Support Reactions, Bearings, Behaviour of Bridge Superstructure.**

1. INTRODUCTION

The study of bridge engineering is an entrancing subject for civil engineer. Bridge is a structure which connects the two points separated by an obstacle without any changes in the obstacle or closing the obstacle. The obstacle may be water bodies, valley, roadway, railway, city, rough terrains, etc. Bridge is one of the most significant component of transporting system and also it saves more time during transportation.

The materials used in the bridge may be natural or manmade materials. During ancient times they used naturally and locally available material such as wooden logs, stones, etc. But now a days bridge material is mainly depends upon, weather the bridge is permanent or temporary. For temporary bridges timber is the basic material, but for permanent bridges material is concrete, steel, stones, PSC, composite material, etc. using advanced equipment during construction.

1.1 History of Bridge Development

Construction of bridges is not a new science. Since as per reference earliest bridge available across Nile-river built in about 2650 BC. The giant trees felling across natural streams were the simple bridges to cross streams for ancient peoples and that was the basic idea for them to development of bridges. From this idea they started using timber as basic material for bridge building and this has been followed by bridge construction with naturally available stones. Indians developed the idea of suspension bridge for pedestrians by using ropes for suspension and wooden planks, bamboo for decks. But they have not kept any record as proof.

1.2 Present Trend of Bridges

Japanese have Akashi-Kaikyo Bridge. It is the longest bridge (Cable and suspension bridge) with a record of 1991m central span. China introduced some notable tied arch bridges in the last few decades. India also have some notable cable stayed bridges and large steel arch bridge in Jammu and Kashmir.

2. COMPONENTS OF BOWSTRING GIRDER BRIDGE

The Components of Bridge consisting of mainly two parts viz. Substructure and Superstructure.

Superstructure: Generally structure lies above bearing is superstructure. It receives loads (dead and moving loads) directly and transfers on to the supports. It behaves most of the times as dynamic member. The Bow-string girder bridge consisting of Bottom chord, Top arch, Hangers, Bottom cross beams, Top bracings and deck. The top arch reduces the horizontal thrust to as less as possible by transferring it directly on to the support as vertical force.

Substructure: It consisting of Pier, abutment and suitable foundation. The main function of pier and abutment is receiving loads safely from superstructure and transferring it to the foundation. The foundation transfers load to the soil through soil-structure interaction.

The components of the bowstring girder bridge in shown in the (Figure 1).

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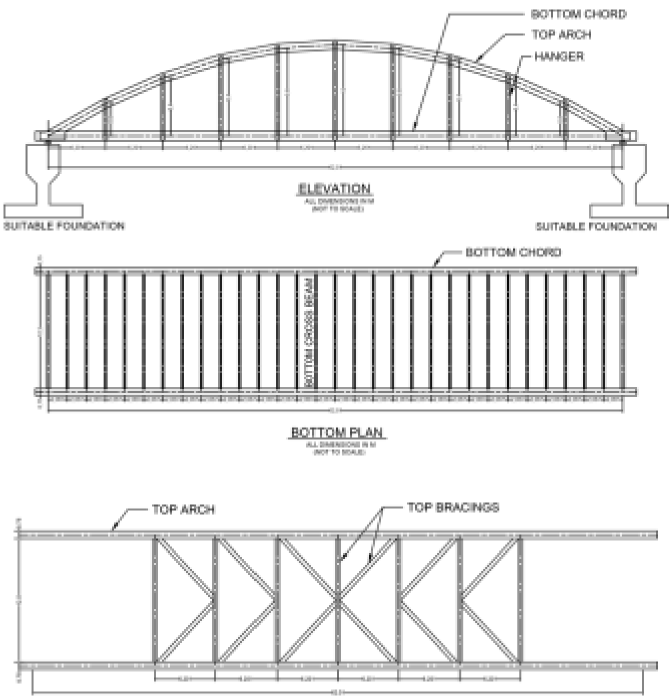

Top Plan

Fig-1: Bowstring Girder Bridge Plan and Elevation

2.1 Bowstring Girder Bridge

Bow-string Girder bridge is a combination of both arch bridge and suspension bridge. In this case the arch is above the deck level. The deck girders are suspended from the top arch by hangers or ties, therefore it is also known as tied arch bridge.

In case of Bow-string Girder Bridge, the horizontal thrust taken by bottom chord by tension is transferred to the top arch by hangers and top arch transfers it to the supports as vertical load, hence no thrust is transferred to the piers or supports. Therefore it is also suitable for places where restricted spaces available for foundations. This bridge is also suitable for places where more number of spans involved.

Advantages of bowstring girder-bridge.

1) There is no thrust on Piers or abutments.
2) They are extremely strong and strengthens themselves.
3) The bridge can be easily dismantled and reused.
4) High Durability.
5) They can be pre-fabricated in to small units and erected in the field.
6) Advantageous at places where more number of spans exists.
7) Aesthetically these bridges are good.

3. INFLUENCE OF SKEW ON BRIDGES

Behaviour of skewed bridge is quite different from that of a normal bridge. Therefore design of skewed bridge needs slight attention. For skew angle up to 20 degree the behaviour of the bridge is similar to that of a normal bridge, therefore analysis and design of bridge is similar to the straight bridge. Beyond 20 degree support reactions, force distribution in the bridge, behaviour of bridge changes.

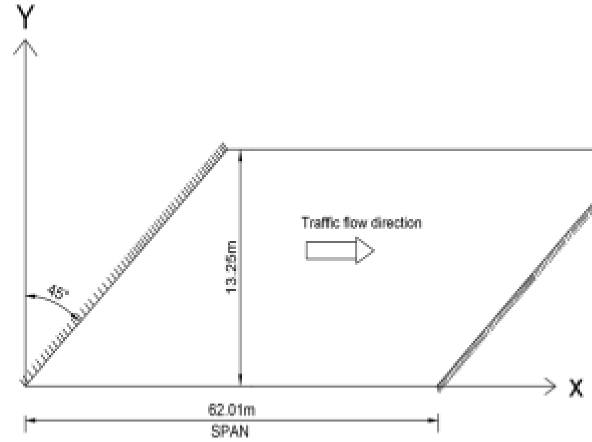

Fig-2: Skew angle showing in bridge plan

In case of Bow-String girder-bridge, the skew effect of bridge deck is taken by two independent arches connected by top bracings. Generally in skewed bridges direction of movement of bearings should be parallel to span and it should not be perpendicular to support. Usually, support reactions at obtuse angle corners is more than the acute angle corners and it depends upon the angle of skew. Creep also induces in deck slab due to skew effect and it is necessary to avoid tension cracks in the deck slab.

4. BRIDGE BEARINGS

Bridge bearings are the devices which are placed or installed at resting surface between bridge superstructure and substructure to transfer dead loads, moving loads, seismic loads, wind loads. Usually bearings isolates the bridge substructure from superstructure, thus most of the shocks absorbed by the bearings. Bearings also reduces the wear and tear of the bridge structure.

Some commonly used bearings

1) Elastomeric bearings: Elastomeric bearings are the most commonly used bearings. These bearings does not have any movable parts but they offer movement and rotation by deformation of elastomeric pad. The elastomer may be natural rubber or neoprene. Some common types of elastomeric bearings are,
   a) Plain elastomeric pad bearings.
   b) Steel reinforced elastomeric pads.
   c) Cotton duck pads (CDPs).
2) Polytetrafluoroethylene (PTFE) Bearing: It is a type of sliding bearing. When horizontal movement is extremely high, then PTFE offers sufficient movement by sliding. PTFE bearings can be used by combination with other bearings like CDPs, disc bearings etc.

   Advantages of PTFE bearing

a) PTFE has low frictional resistance.
b) They are aesthetically good.
c) They show resistance to weathering and corrosion
d) If we place stainless steel plate on PTFE, they offer smooth surface for sliding.
e) PTFE has greater resistance to wear and tear and it can also be used resist higher bearing pressure.

3) POT Bearing: The Pot bearing consisting of shallow steel cylinder or pot with tight fitting elastomeric rubber disc. A mechanical steel piston is fitted in to the steel cylinder, and it rests directly on elastomeric disc and brass rings are used to seal elastomeric disc between the piston and steel cylinder. The entire vertical load from the bridge is carried through the piston and resisted by the elastomeric pad. The elastomeric pad is confined within the cylinder, therefore it is slightly incompressible. The bearing can also offers rotation but it depends upon the deformation of the elastomeric disc.

4) Fabricated steel-bearings: These type of bearing can be used in both fixed and expansion conditions. Most of the existing bridges have these type of bearing. These type of bearing transmits the loads through direct contact of metal with another metal. These bearings are expensive to do fabrication and they also requires maintenance. This bearing offers only unidirectional movement.

5. BRIDGE MODELLING

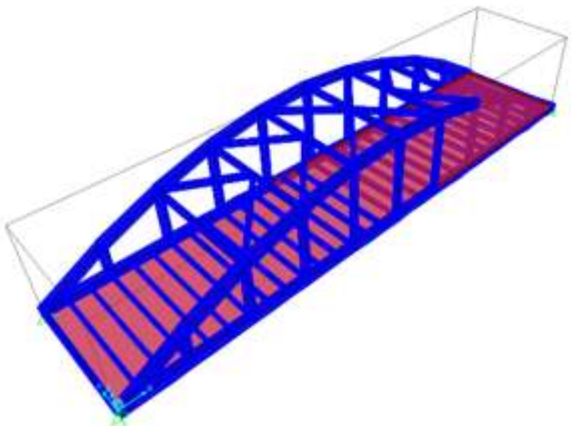

Fig-3:3D Model of the Bridge for 0 degree skew angle

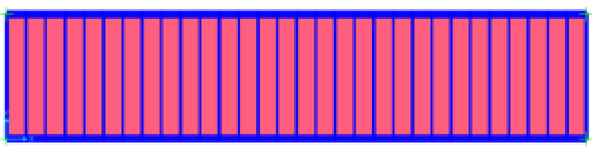

Fig-3: Bottom Plan of the Bridge for 0 degree skew angle

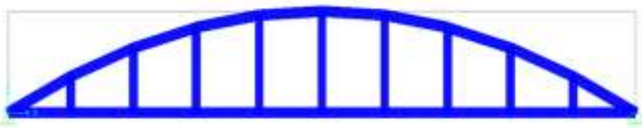

Fig-5: Side View of the bridge for 0 degree skew

The 3D Models (finite element models) of the bridge were developed by using finite element based SAP2000. The Bowstring girder bridge consisting of 2-lane, one way traffic, intended for highway. Overall span of the bridge is 64.01m and effective span of the bridge is 62.01m. The bridge consist road width of 9.5m for vehicular traffic and 1.5m wide footpath for pedestrians. The overall width of the bridge is 14m and effective width of the bridge is 13.25m. Two vehicle paths are defined for vehicular loadings. The height of bridge at crown-point is 10m. The height of hangers is calculated by using parabolic equation. The skew angles considered in this project are 0, 30, 45 and 60 degree.

The bridge superstructure consisting of two main longitudinal bottom chords of rectangular steel box sections connected to the top arch of rectangular steel box section through hangers of box section. The deck slab supported on the bottom cross beams of steel I-section. The two independent arch are connected by top bracing of box section. Crash barrier is provided on either side. The supports provided are hinged supports at one end and roller supports at other end.

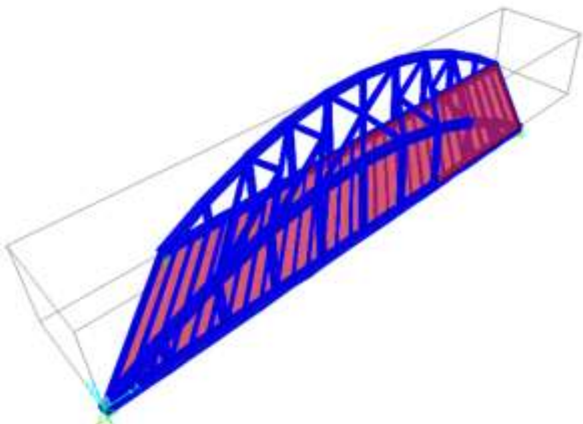

Fig-5:3D Model of the Bridge for4 5 degree skew angle

Fig-5: Bottom Plan of the Bridge for 45 degree skew angle

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5.1 Loading Consideration in Bridge

The loads considered are Self-weight, Super imposed dead load, wearing coat load, footway load, IRC Class A, IRC Class 70R, IRC Class AA tracked, IRC Special vehicle loading.

5.2 IRC Vehicle Path Details

The bridge deck consists 9.5m wide carriage way (two lane, one-way traffic), therefore two paths namely PATH 1 and PATH 2 are defined. IRC vehicles moves on these paths only. PATH 1 is located at a distance of 3.4m and PATH 2 is located at a distance of 8.15m from the centre line of right bottom chord. Effective distance between two paths is 4.75m. The centre line of the paths are located at a distance of 2.375m from the face of the crash barrier on either side.

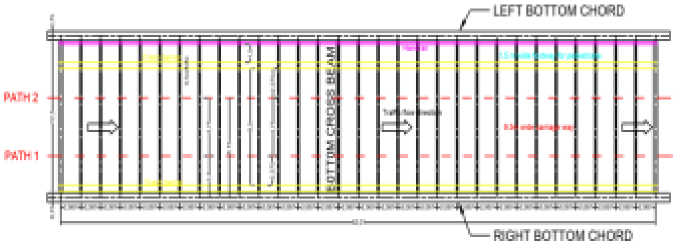

Fig-6: IRC Vehicle Path shown in Plan

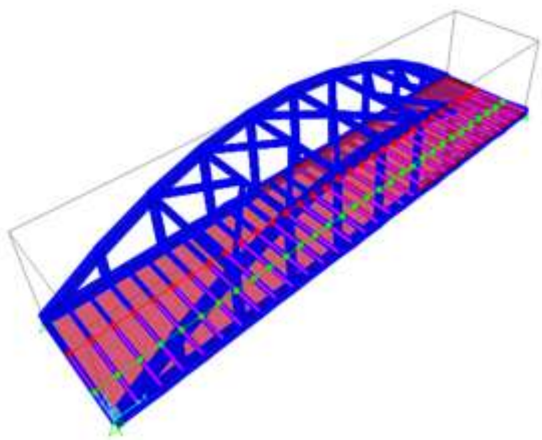

Fig-7: IRC Vehicle Path defined using SAP2000

5.3 IRC Live load combinations

From IRC: 6-2014, Table No.2 live combinations and loading arrangement are defined. IRC Class A vehicle moves on both paths at same time and other vehicles travels on only one path at each time in case of two lane traffic. The special vehicle load is considered for design of new bridges. During the passage of special vehicle no other vehicle is considered to pass on the bridge. The factor of safety for SV loading is taken as 1.

After checking the proper modelling and loading the analysis has been carried out by using SAP2000 and results are listed.

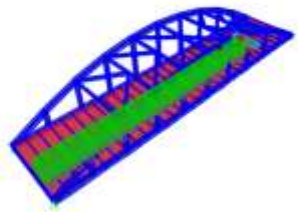

Fig-8: IRC Special vehicle moving on Path 1

6. RESULTS AND DISCUSSIONS

After modelling, loading and analysis, the results obtained from the analysis part are noted carefully. The results may be Predominant axial forces in the bottom chord, top arch, top bracings, hangers and bending moment, shear force in bottom cross beams below the deck slab. Graphs are plotted from the data noted and compared for the skew angles 0, 30, 45 and 60 degree.

6.1 Design Axial Force in Right bottom chord is Compared with skew Angles.

Table-1: Design Axial Force from combination of loads

DISTANCE ALONG SPAN,m	DESIGN AXIAL FORCE in kN, Tension			
	0 degree	30 degree	45 degree	60 degree
0	5742.63	6304.995	7287.56	7992.02
10	3889.16	4736.34	5323.5	6918.22
20	3646.21	3637.45	3760.64	4736.08
30	3723.36	3625.12	3543.88	3543.73
40	3614.69	3717.4	3664.33	3453.48
50	3769.68	3830.57	3799.9	3566.85
60	5874	5035.99	4598.37	4100.012

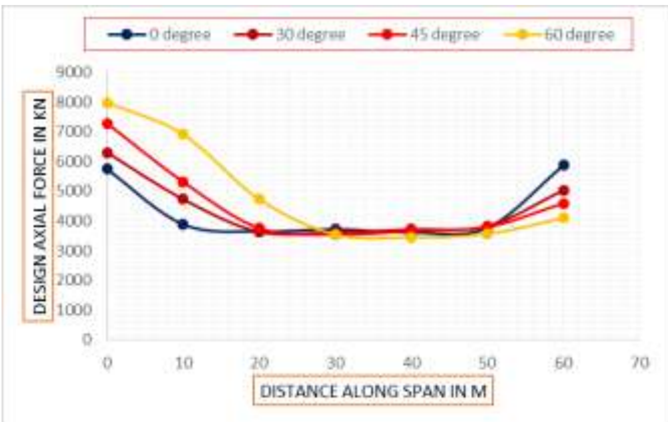

Chart-1: Design Axial Force in Right Bottom Chord

From the above (chart 1) it is observed that the predominant axial force in the bottom chord ends is larger than the axial force in the middle. The axial force in the bottom chord end towards acute angle corner is more than the axial force in the bottom chord end towards obtuse angle corner and increases with the increase in skew angle. But axial force in bottom chord end towards obtuse angle corner decreases with the increase in skew angle. The force in bottom chord is tensile in nature.

6.2 Design Axial Force in Left bottom chord is Compared with skew Angles.

Chart-2: Predominant Axial Force in Left Bottom Chord

From the above (Chart 2) it is again observed that predominant axial force in the bottom chord end towards acute angle corner increases with the increase in skew angle. But at the other end axial force decreases with the increase in skew angle.

6.3 Design Axial Force in Top arch is compared With skew Angles.

Chart-3: Predominant Axial Force in Top Arch(Tension)

From the above (Chart 3) it is observed that predominant axial in the top arch at ends is greater than the axial force in the middle. At middle the axial force increases with the increase in the skew angle. For 60 degree skew angle the predominant axial force in the top arch end towards acute angle corner increases and at the other end decreases.

6.4 Design Axial Force in Hangers is compared with Skew Angles.

The predominant axial force in hanger next to end hanger towards acute angle corner increases with the increase in skew angle. But at the other end axial force decreases with the increase in skew angle.

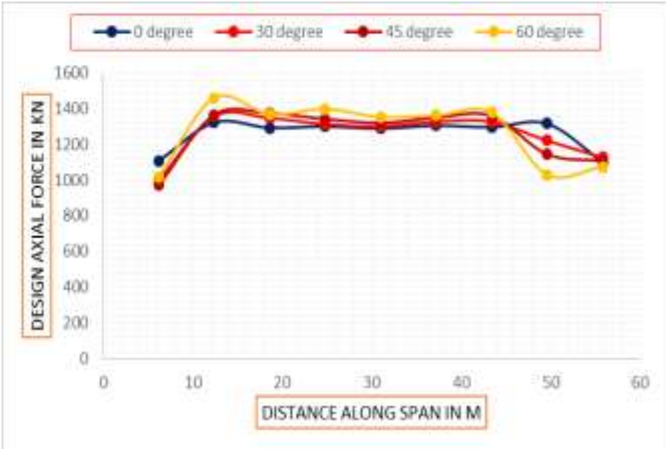

Chart-4: Predominant Axial Force in Hangers(Tension)

6.5 Design Axial Force in Top bracings is compared With Skew Angles.

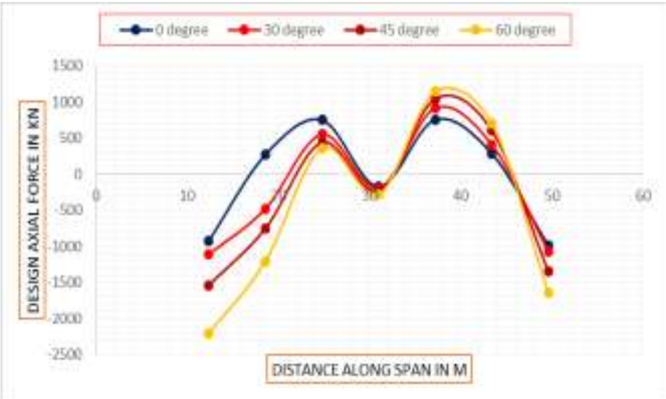

Chart-5: Predominant Axial Force in Top Bracings

Top bracings takes both compression and tension. The sign convention is, the positive sign indicates Tension and negative sign indicates Compression. The middle and end top bracing takes always compression for all skew angles.

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6.6 Bending Moment in Bottom Cross Beams is Compared with the Skew Angles.

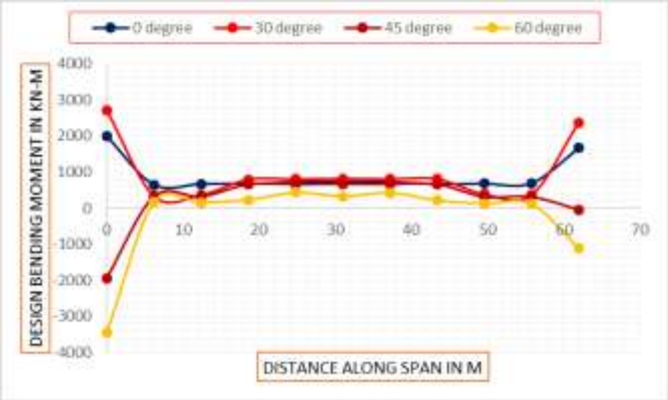

Chart-6: Bending Moment in Bottom Cross Beams

Bending moment in the end beams is greater than the bending moment in the middle beams and increases with the increase in skew angle. Beyond the 30 degree skew angle the bending moment changes from positive to negative in the end beams.

6.7 Shear Force in Bottom Cross Beams is Compared with the Skew Angles

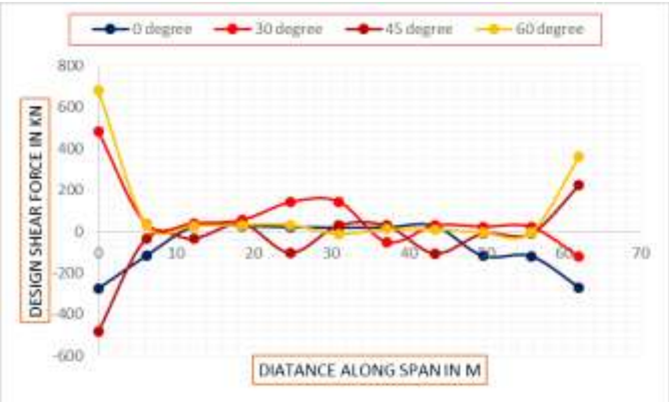

Chart-7: Shear Force in bottom Cross Beams

Shear force in the end beams is larger than the shear force in the middle beams and increases with the increase in skew angle. Shear force at the beam starting the vehicle movement is larger than the beam at which vehicle leaves with the increase in skew angle.

7. SUPPORT REACTIONS

The type of supports provided are hinged and roller supports. Hinged supports are provided at position 1 and 2, roller supports are provided at position 3 and 4 as shown in the figure below. Hinged supports resists the vertical and horizontal forces but not moment. Roller supports resists only vertical force.

Table-2: Vertical Reaction at each Support

SUPPORT No	SUPPORT TYPE	VERTICAL REACTION, V in kN			
		0 degree	30 degree	45 degree	60 degree
1	HINGED	6616.7	6520.5	6600.0	6885.8
2	HINGED	5046.6	5424.6	5700.4	6081.7
3	ROLLER	6529.1	6808.7	7010.8	7247.5
4	ROLLER	5013.3	4715.2	4682.2	4789.6

Note: Sign convention- Upward vertical reaction is taken as positive and downward reaction is taken as negative. Right horizontal force in x-direction is taken as positive and left is negative. Forward horizontal force in y- direction is taken as positive and backward is taken as negative

Table-3: Horizontal Force (H_y) at each Support.

SUPPORT No	SUPPORT TYPE	HORIZOTAL FORCE, Hy in kN			
		0 degree	30 degree	45 degree	60 degree
1	HINGED	-1449.4	-1033.1	-903.6	-656.7
2	HINGED	1449.4	1033.1	903.6	656.7
3	ROLLER	-	-	-	-
4	ROLLER	-	-	-	-

Table-4: Horizontal Force (H_x) at each Support

SUPPORT No	SUPPORT TYPE	HORIZOTAL FORCE, Hx in kN			
		0 degree	30 degree	45 degree	60 degree
1	HINGED	-	-596.4	-903.6	-1137.7
2	HINGED	-	596.4	903.6	1137.7
3	ROLLER	-	-	-	-
4	ROLLER	-	-	-	-

From the above tabulation it is observe that the for uniformly distributed dead load vertical support reaction is predominate at obtuse angle corner and also increases as the skew angle increases. At acute angle corner the support reaction is slightly smaller than that of an obtuse angle corner. But in case of IRC loading the support reaction depends upon the vehicle path location from support. When IRC vehicle path is defined close to support, it covers both obtuse and acute angle corners at same time. Therefore as the vehicle enters bridge at acute angle corner, through path defined and simultaneously it leaves the bridge at obtuse angle corner and vice-versa. In such cases the support reactions at obtuse angle corner is larger than the acute angle corner and gradually increases at the obtuse angle corner as the skew angle increases. At acute angle corner the support reaction increases slightly as skew angle increases. Horizontal forces at hinged supports increases as the skew angle increases. Horizontal forces at both hinged supports in both x and y direction are equal and opposite for 45 degree skew angle.

For above observed vertical reaction and horizontal forces are large, therefore suggested bearing is POT cum PTFE. The bearing movement and its position is shown

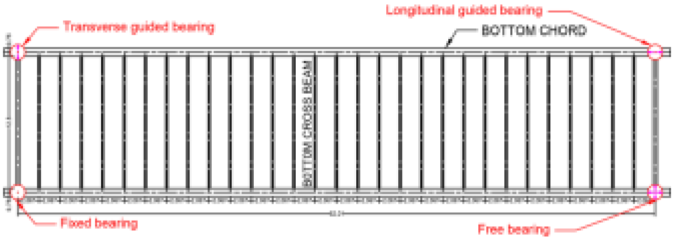

Fig-9: Position and Movement of Bearings

8. CONCLUSIONS

The effect of skew angle on the behaviour of Bowstring girder-bridge is briefly described in this project. The behaviour include predominant axial force in bottom chords, top arches, hangers and top bracings is considered and predominant bending moment and shear force is considered in bottom cross beams. The skew angles considered for study is 0 degree, 30 degree, 45 degree and 60 degree. The effect of skew angle on the support reactions also discussed in this project. From the above discussion, following conclusions are concluded.

1) The predominant axial force in the bottom chord end close to acute angle corner is more than the other end close to obtuse angle corner.
2) The predominant axial force in the bottom chord end towards acute angle corner increases as the skew angle increases. But axial force in the bottom chord end towards obtuse angle corner decreases as the skew angle increases.
3) The predominant axial force in the ends of the top arch is greater than the axial force at middle of top arch for all skew angles.
4) Up to 45 degree the axial force in the ends of top arch is similar to normal bridge but, at middle the axial force is slightly increases with increase in skew angle.
5) For skew angle beyond 45 degree the axial force in top arch at acute angle corner increases and towards obtuse angle corner the axial force decreases.
6) The predominant axial force in the end hangers of straight bridge less than the predominant axial force of any other hanger.
7) The predominant axial force in the hanger next to end hanger towards acute angle corner is more than the any other angle and it increases with the increase in skew angle. But predominant axial force in the hanger next to end hanger towards obtuse angle corner decreases with increase in skew angle and it falls below the value of end hanger for 60 degree skew angle.
8) The top bracings takes both compression and tension alternatively. The top bracing member at middle of the bridge takes almost similar compression value for all skew angles.
9) Bending moment increases with increase in skew angle. The bending moment in end beam is larger than the middle beams.

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