STUDY OF STATIC ANALYSIS ON CONVENTIONAL AND OBLIQUE PRESTRESSED CONCRETE BRIDGE SUPERSTRUCTURE

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Abstract - *Today the bridge construction has a worldwide level of importance. Bridges are the key elements in any road network, and use of prestress girder type bridges are most popular in bridge engineering zone why because of its better stability, serviceability, economy, aesthetic appearance and structural efficiency. The use of prestressed concrete pavement has some greater advantages and that can reduce slab thickness, eliminate transverse joints and enhance durability compared to traditional concrete pavement. Conventional prestressing or precast prestressing in the longitudinal direction requires additional space for anchorage and adds more joints. This study proposes an oblique prestress concrete bridge superstructure, in which prestressed tendons were distributed with an angle (45^0) to the road direction so that the prestress can be applied in the transverse direction. Also compare the two methods of application of prestressing with the help of software CSi Bridge. Analysis of sections was also conducted. Oblique prestressing with 1m and 2m spacing is modeled and analyzed for the purpose of study the effects of increment in spacing.*

Key Words: Conventional Prestressing, Oblique prestress, tendons, transverse joints, CSi Bridge,

1. INTRODUCTION

Prestressed concrete combines high strength concrete with high strength steel in an “active” manner. This can be achieved by tensioning the steel and holding it against the concrete, thus putting concrete into compression and is done to improve the performance of the concrete in service. The most widely used prestressing approach is post-tensioning in the longitudinal direction in the early stage. This technique requires some space for the anchorage area at the two ends of the sections. In the oblique prestressing or cross tensioned method, the prestressed tendons are distributed obliquely with an angle in the road direction so that the prestressing can be applied in transverse direction. By adjusting the angle, the proportion of prestressing in the transverse direction can be changed. The prestressing in the transverse direction provides lateral constraints to the slab so that the transverse joints can be eliminated. The anchorage area is on the side of the concrete slabs so that long concrete slabs can be achieved without sacrificing the prestressing. Finally the oblique prestressing on concrete slabs can be used in achieving long span bridges without providing prestressing on girders. [9]

1.1 Objectives

- To design the proposed bridge superstructure including conventional prestressing
- Modeling the conventional and oblique prestressed concrete bridge superstructure and analyze using CSi Bridge software
- To study the effects of increasing tendon spacing in oblique prestressing
- To compare the result of static analysis of 2 types of prestressing

1.2 Scope

This project is limited on designing and analyzing a prestressed concrete bridge and the deck slab including approach roads with the use of IRC code. And it doesn’t cover hydraulic design and geotechnical design.

2. LITERATURE STUDY

Ling Yu et.al proposes an oblique prestressed concrete pavement design criteria. Prestressed concrete pavement can reduce slab thickness, eliminate transverse joints and enhance durability compared to traditional concrete pavement. Traditional prestressing or precast prestressing in the longitudinal direction requires additional space for anchorage and adds more joints. This study proposed an oblique prestress concrete pavement, in which prestressed tendons were distributed with an angle to the road direction so that the prestress can be applied in both the transverse and longitudinal directions. The detailed design of the oblique prestress concrete pavement, including the selection of raw materials, design of cement concrete, anchorage area, size and distribution of prestressed tendons, stress analysis within the concrete slab, sliding layer, side reinforcement, and regular reinforcement at top and bottom are all included in this study. The slab thickness, diameter, distribution angle, and spacing of tendons were obtained based on the stress analysis to meet the requirement of fracture criteria and fatigue criteria. How the oblique prestressing is to be provided in deck slab are as shown in figure 2.3. In addition, the transverse prestress is beneficial to resist the traffic related slab deformation, the tendon distribution angle is varies from 25° to 45°. In terms of the spacing, tentative values were used are: 0.5 m, 0.8 m, and 1.0 m.

Advantages of prestressing are, High-strength concrete and high-tensile steel, besides being economical, make for slender sections, which are aesthetically superior. Prestressed concrete bridges can be designed as class I type structures without any tensile stresses under service loads, thus resulting in a crack-free structure. Prestressed concrete is ideally suited for composite bridge construction in which precast prestressed girders support the cast in situ slab deck. This type of construction is very popular since it involves minimum disruption of traffic. Post-tensioned prestressed concrete finds extensive applications in long-span continuous girder bridges of variable cross-section. Not only does it make for sleek. Structures, but it also effects considerable saving in the overall cost of construction. [1]

3. METHODOLOGY

For the purpose of study an established details of a new bridges at Kozhancherry area are to be selected. Kozhencherry is a census town in Pathanamthitta district of Central Travancore region (South Central Kerala) in Kerala state, South India. It is on the banks of river Pampa. As per the part of eliminating the traffic congestion in Kozhencherry bridge a new bridge layout has to be proposed. As per the new proposed bridge, that has 207.2 meters long and 7.5 meters wide and 1.125 m wide walkway. The bridge is made up of five spans in length 32 meters and two 23.6 meters long end spans. 600mm wide kerbs are to be provided on each side. Thickness of wearing coat is 80mm. IRC Class AA tracked vehicle loading is to be considered for the design. For deck slab and prestressed girders adopt, M45 grade concrete for construction. Analysis of the bridge sections were done with the use of CSi Bridge software. Again the oblique prestressing is applied to the same model and also reduces the bridge section dimension. Then analyze the model and ensure that the section provided was satisfied or not.

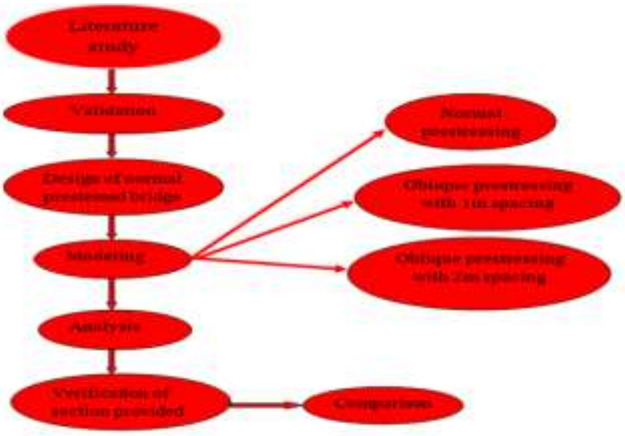

Table –1: Dimensions of conventionally prestressed concrete bridge superstructure

Bridge components	Description	Dimensions(mm)
Deck slab	Thickness	200
Girder	Flange	500 x 400
	Web	1320 x 200

As part of the study firstly, the conventionally prestressed bridge superstructure were modeled and then analyzed. Conventional prestressing means that prestressing tendons were placed in longitudinal direction and follows the parabolic path. And the superstructure consists of 4 girders (2 internal and 2 external) to support the deck slab. The light green portion in the below figures indicates the prestressing tendon profiles.

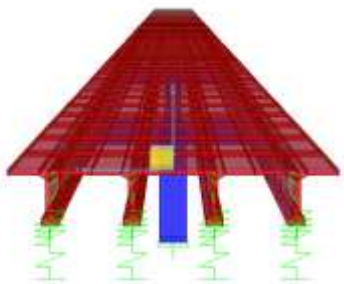

Fig -1: Front view model of conventional prestressed bridge superstructure

Table –2: Properties of materials used

Material	Grade	Poisson's ratio	Density (N/mm²)
Concrete	M-45	33.5×10^3	2.4×10^{-6}
Steel	M-45	2×10^5	7.85×10^{-6}

Table- 3: Mechanical properties of prestressing strands

Dimensions	15.2 mm dia. 7- ply high tensile strands
Class	I type
Area (A_p)	139.4 mm²
Weight	1.094 kg/m
Ultimate tensile strength (f_p)	1723 N/mm²

3.1 Boundary Conditions

Displacement boundary conditions are needed to constrain the model to get a unique solution. To ensure that the model acts as the same way as the experimental bridge, boundary conditions needed to be applied at points of symmetry and where the supports and loading exist. In traditional construction, the bearings are typically the controlling feature of a seismic design and the piers or abutments are assumed to be fixed.

3.2 Loading and Analysis

Live load is taken as IRC class AA tracked type loading. According to IRC Class AA tracked loading the total load is 700 kN. In CSi Bridge software there is an option for programme defined vehicular classes of different codes. Vehicles are used to define the moving loads in CSiBridge and are most often defined to act on the traffic lanes. There are standard types of vehicles in the program, or users can design unique vehicles using the general vehicle specification. Vehicle classes are sets of one or more vehicles that can be assigned to act on lanes in a moving-load case. Railing load are distributed as point loads on the left and right edges. Load due to wearing coat are distributed as area load over the entire deck slab section. The definition of moving vehicular load is shown in the figure below. And the critical combinations of loads are (1.5dead load + 2.5 live loads).

3.3 Modeling of Oblique prestressed bridge super structure

In the normal prestressing the prestressing tendons are provided in the longitudinal direction while in oblique prestressing the tendons were provided obliquely with an angle in the direction of road. As name indicates the tendons are distributed in the deck slab of the bridge. In this type of tendon profile pattern numerous numbers of strands were placed, that behaves like a mesh. As part of the study the 2 models were created and analyzed. First model consist of tendons with 1m spacing and second model consists of tendons with 2m spacing. According to literatures the tendon spacing varies from 0.5m to 1m. And the tendon distribution angle from 25° to 45°.But for studying the effects of increment in spacing the model with 2m spacing and 45^0 distribution angle is created. In this model, the 2 interior girders were eliminated and the slab thickness were reduced, that is only 150mm thickness of slab is provided. And then analysis was done. Straight tendon profile is followed in this model. And Material properties and mechanical properties are same as in normal prestressing. The elimination of girder and reduction in slab thickness is done with respect to the literatures available. Finally check the section provided is safe or not.

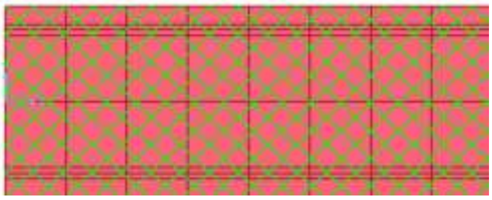

Fig -2: Plan of oblique tendons in each span

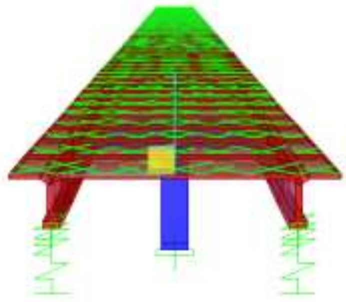

Fig -3: Front view of oblique prestressed bridge superstructure

3.3.1 Varification of Section Provided in Oblique Prestressing

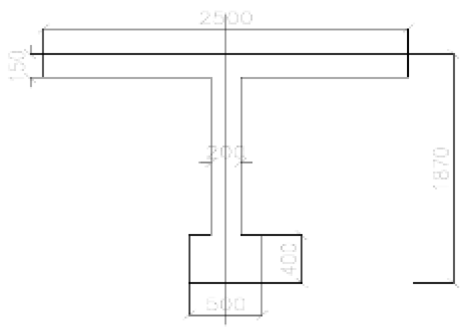

Fig -4: Cross section of main girder

A = (2500 x 150) + (200 x 1320) + (400 x 500)

= 83.9×10^4 mm^2

$$y_t = \frac{\left(2500x150x\frac{150}{2}\right)+\left(1320x200x\left(150+\frac{1320}{2}\right)+\left(500x\,400x\,(1470+\frac{400}{2}\right)\right.}{83.9x10^4}$$

= 686.48 mm

y_b = 1870-686.48 = 1183.52 mm

h_1= 686.48 - $\frac{150}{2} = 611.48\ mm$; h_2 = 686.48 – 810= -123.52 mm and h_3 = 686.48– 1670 = -983.52 mm

I_{xx1} =

$$\left[\frac{2500x\,150^3}{12}+\left(200x150x\,611.48^2\right)\right] = 1.192\ x\ 10^{10}\ mm^2$$

I_{xx2} =
$$\left[\frac{200x\,1320^3}{12} + (200x1320x123.52^2)\right] = 4.236\ x\ 10^{10}\ mm^2$$

I_{xx3} =
$$\left[\frac{500x\,400^3}{12} + (500x400x983.52^2)\right] = 1.9612x\ 10^{11}\ mm^2$$

$$I\ = 1.192\ x\ 10^{10} + 4.236\ x\ 10^{10} + 1.9612x\ 10^{11}$$

$$= 2.504\ 10^{11}\ mm^4$$

$$Z_t = \frac{I}{y_t} = \frac{2.504x10^{11}}{686.48} = 364.759\ x\ 10^6\ mm^3$$

$$Z_b = \frac{I}{y_b} = \frac{2.504x\,10^{11}}{1183.52} = 211.57\ x\ 10^6\ mm^3$$

Results taken from software;

M_g = 3170.0842 kNm and M_q = 1144.2184 kNm

η = 0.85

f_{br} = 17 N/mm²

$Z_{b\ (required)}$;

$$\frac{M_q + (1-\eta)M_g}{f_{br}} = \frac{[1144.2184 + (1-0.85)x\,3170.0842]}{17}\ x\ 10^6$$

$$= 95.27\ x\ 10^6\ mm^3 < 211.57\ x\ 10^6\ mm^3$$

$Z_{b\ (required)} < Z_{b\ (provided)}$

Hence the section provided is safe for the design.

4. RESULT AND DISCUSSION

Static analysis was carried out for the conventional prestressed and obliquely prestressed concrete bridge superstructure with 1 meter and 2 meter spacing. Displacement, shear and moment values were obtained for the respective bridges for comparison.

4.1 Conventional prestressed bridge

4.1.1 Maximum shear

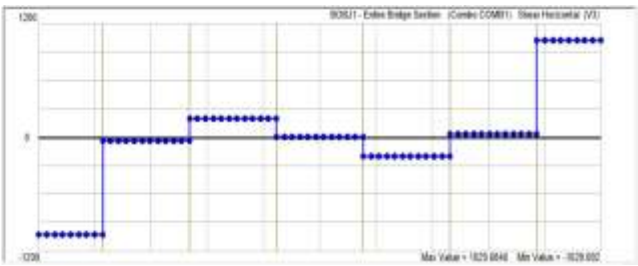

Fig- 5: Bridge response plot for maximum shear value

4.1.2 Maximum moment

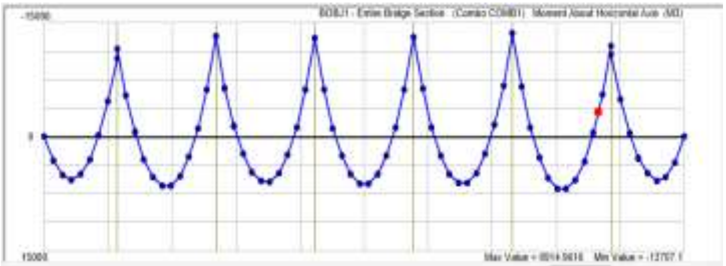

Fig-6: Bridge response plot for maximum moment

4.1.3 Maximum displacement

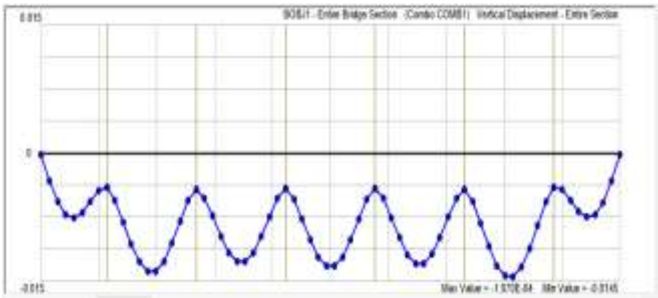

Fig-7: Bridge response plot for maximum displacement

4.2 Oblique prestressed bridge with 1m spacing

4.2.1 Maximum shear

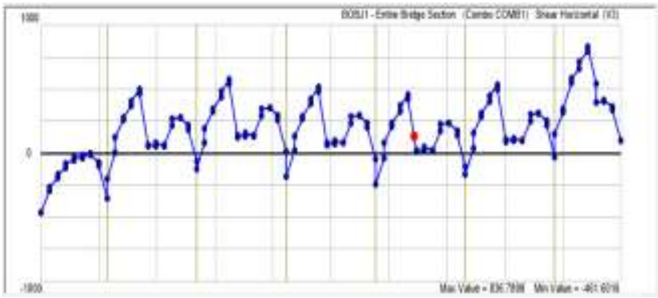

Fig -8: Bridge response plot for maximum shear value

4.2.2 Maximum moment

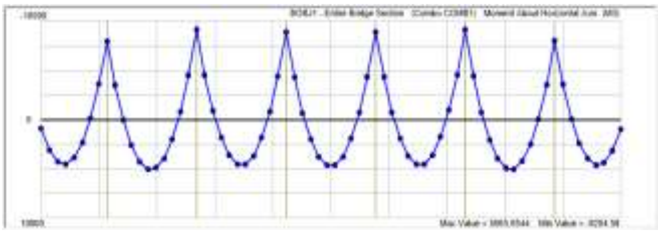

Fig -9: Bridge response plot for maximum moment value

4.2.3 Maximum displacement

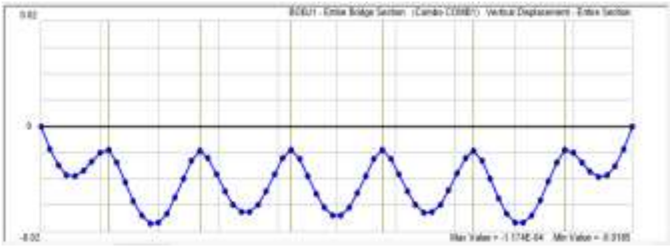

Fig -10: Bridge response plot for maximum displacement

4.3 Oblique prestressed bridge with 2m spacing

4.3.1 Maximum shear

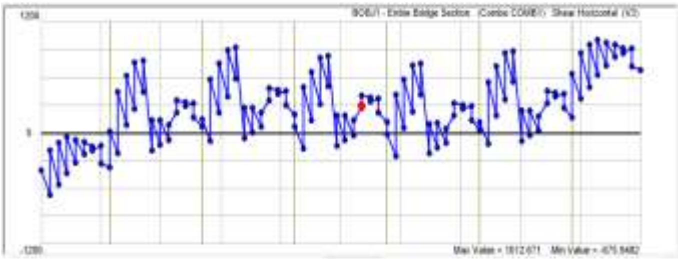

Fig -11: Bridge response plot for maximum shear value

5.3.2 Maximum moment

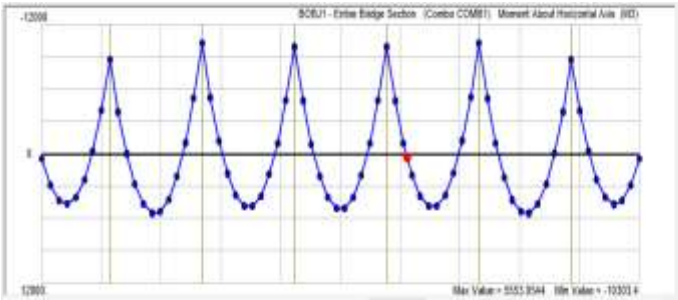

Fig -12: Bridge response plot for maximum moment value

5.3.3 Maximum displacement

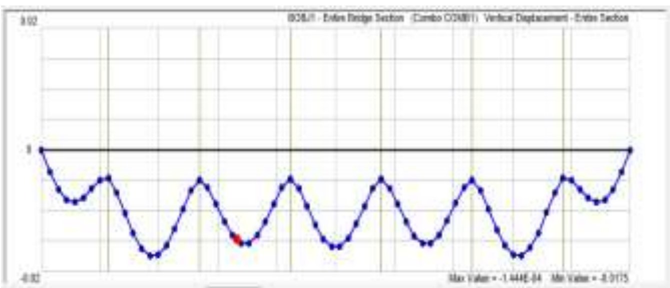

Fig -13: Bridge response plot for maximum displacement

Table -4: Comparison of results

Parameter	Conventional prestressing	Oblique with 1m spacing	Oblique with 2m spacing
Shear force (kN)	1029.6846	836.7898	1012.671
Moment (kNm)	6914.9616	5065.9544	5553.0544
Displacement (m)	1.97 x 10^{-4}	1.174 x 10^{-4}	1.444 x 10^{-4}

From the above data, the total shear force and bending moment for conventional prestressing are 1029.6846 kN and 6914.9616 kNm respectively. While in oblique prestressing the shear and bending moment will reduces. In oblique prestressing with 1metre spacing the shear and moment are 836.7898 kN and 5065.9544 kNm respectively. There will be a greater reduction in shear and bending moment value while comparing with conventional prestressing. This effect is due to improved stiffness in the transverse arrangement of tendons in oblique prestressing. In oblique prestressing the dead weight imparted by prestressing tendons will increase than from conventional prestressing. But the dead weight due to concrete sections such as, slab and interior girders will reduce. Why because the 200mm thick slab will be reduced into 150mm thick slab and 4 numbers of girders will be reduced into 2 numbers of interior girders. There is another advantage in case of oblique prestressing is that, the total cost of the structure can also be reduces. Why because while providing oblique prestressing the number of girders can be eliminated and also the slab thickness will be reduced in a great extent. So that the cost of construction will decreases as compared to conventional prestressing.

In addition, the transverse prestress is beneficial to resist the traffic related slab deformation. In oblique prestressing the anchorage to prestressing tendons were provided on transverse direction that is on the either sides of the slabs where as in conventional prestressing that was provided in the longitudinal direction at each segmented sections. So that in normal prestressing the space in between each segmental section provided will be higher why because there should be enough space for anchorage. That will increases the prestressing loss in case of long span bridges and also it limits the length of the bridge section. In oblique prestressing only conventional expanded joints were provided in order to reduce the deformation of slabs. In oblique prestressing the anchorage to tendons were imparted through the sideways of the slab section and not in longitudinal direction. And also the mesh arrangement will obtained and this improves the strength and reduces the moment in a great extent. Also that will reduce the depth of the slab; it will also decrease the total dead weight.

According to Indian standards, the allowable deflection in bridge structure should not be greater than (Span/ 1000). So the allowable deflection is to be, (32/1000 = 0.032m). Here the maximum deflection is 1.97 x 10^{-4}m. Hence the deflection is within the allowable limit. The displacement in conventional prestressed bridge is 1.97 x 10^{-4} m. And in oblique prestressing with 1meter spacing is 1.17 x 10^{-4}m. In oblique with 2 meter spacing the displacement is 1.44 x 10^{-4} m. From these results, the displacement value of the oblique prestressing will be lesser as compared to conventional prestressing. The oblique prestressing with 2 meter spacing shows slightly higher displacement than from oblique prestressing with 1meter spacing. Hence the spacing of tendons in oblique prestressing beyond 1meter increases not only the shear force and bending moment but also the displacement. But it never cross the displacement due to conventional prestressing.

According to literatures, the tendon distribution angle varies from 25^0 to 45^0. The tendon distribution angle greatly affects the ratio of longitudinal stress and transverse stress. A higher tendon distribution angle is expected to bring higher longitudinal stress and lower transverse stress. Typically, a higher longitudinal stress is desirable because it demands a smaller tendon distribution angle. A low tendon distribution angle would be more challenging to design and construct the anchorage area. So that distribution angle of 45^0 was chooses for the modeling. From literatures, an increase in space from 0.5 m to 1.0 m would result in lower longitudinal and transverse stresses. For study the effect what will occur when the spacing is increased beyond 1m a parallel study was conducted, so the oblique with 2m is taken into consideration. And from the results, the oblique with 2m spacing posses larger shear and moment as compared to oblique with 1m spacing. Finally concluded that, when the spacing increases beyond 1m the effects will have reverse effect, that means the moment and shear force will gradually increases. In terms of the effect of tendon spacing on the stress level in the concrete slab, it can be realized that an increase in space from 1.0 m to 2.0 m would result in higher longitudinal and transverse stresses. This is paralleled with expectation since a larger spacing (from 0.5m to 1m) results in a lower reinforcement rate and therefore, lower load on the concrete slab and the spacing from 1.0 m to 2.0 m the loads become higher.

4. CONCLUSIONS

In this project, the static analysis of the conventional prestressed, oblique prestressed with 1m spacing and oblique prestressed with 2 m spacing were modeled and analyzed. The static analysis was carried out to find the shear force, moment and displacement of the corresponding structure. The structural modeling and analysis was done using the software CSi Bridge. Only the superstructure contains deck slab and girders were modeled. For the supports of structure simply provided the abutments as fixed supports. In this work the comparison of static performance of the above mentioned 3 type bridge superstructure were taken. The result of the analysis reveals that the oblique prestressed bridge performs well during their life period as compared to the other two. The following major conclusions were drawn based on the studies carried out under this study;

* In conventional prestressing, the prestressing tendons were provided in longitudinal direction. Most probably the tendons were placed along girders. In case of long span bridges, the prestressing will be done by using end blocks and anchorage were provided on the ends of each segment. So large space will needed in between each segments. This will increases the prestress loss and also it limits the length of the bridge section.

* While in oblique prestressing the tendons were provided in transverse direction. Oblique prestressing can be provided only along the slab section. In this case the end blocks are located at certain intervals on either side of the slab section. So the spacing in between segments can eliminate.

* In oblique prestressing the prestressing tendons were placed at an angle along the road direction at certain intervals. A mesh like arrangement of tendons were obtained, that will impart high pretension force through the slab section

* Through oblique prestressing the depth of slab can be reduced. And also it eliminates the requirement of large number of interior girders. The design bending moment value from the analyzed model is taken, and the section provided is checked which is safe or not.

* The shear force and bending moment value of oblique prestressing is decreased in a greater extent (around 18 %) as compared to the conventional prestressing

* When the spacing of prestressing tendons in oblique prestressing increased beyond 1.0 meter, the moment and shear value will shows a declining effect.

* A low tendon distribution angle would be more challenging to design and construct the anchorage area. So that distribution angle of 45^0 provides the better result.

* The displacement value of the oblique prestressing will be lesser as compared to conventional prestressing.

* The oblique prestressing with 2 meter spacing shows slightly higher displacement than from oblique prestressing with 1meter spacing. Hence the spacing of tendons in oblique prestressing beyond 1meter increases not only the shear force and bending moment but also the displacement. But it never crosses the displacement due to conventional prestressing.

* Hence finally concluded that, the oblique prestressing with 1.0 m tendon spacing has better prestressing effects as compared with conventional prestressing.

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