SUSTAINABLE COST OPTIMIZATION OF MULTI SPAN BRIDGES AND FLYOVERS

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Abstract

India is a fast developing nation in with a lot of construction activities in the infrastructure developments including roads railways and public utilities etc. Bridges and flyovers are the integral part of the roads and railways for the connectivity and ease of traffic. The history of the construction of concrete bridges in India is century old. In the case of construction of pre stressed concrete bridges also India has got a prominent role. In older days technology was not much developed and manual means were much implemented for the construction of bridges. Nowadays construction methodologies have been changed widely and sophisticated machineries are introduced which made the labour input to a minimum. But the overall construction cost is on the high. The main reason for the high overall construction cost is the lack of study at the planning stage. Subsequently all the flaws are cumulated and resulted in the high construction cost. This can be reduced to a great extent by implementing optimization techniques particularly in the planning and design stages. As far as a particular bridge site is concerned the unit cost of material, labour and machinery etc. are constant. So the cost effectiveness can only be achieved by the optimization of the design in consideration with the site related parameters. In this study the various factors which influence the higher cost of construction are elaborated and a real time approach to reduce the overall construction cost are discussed with. Apart from the cost considerations this will be particularly beneficial to the sustainable development by the minimum use of materials and energy thus preserving the ecology and environment to a possible extent. From this study it is inferred that the overall construction cost can only be achieved by utilizing the piles at its maximum capacity and the span length should be decided based on the various combinations of number of piles in a group.

***Keywords**: Multi span bridges, sustainable development, cost optimization, pile capacity*

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1. INTRODUCTION

From the beginning of the 20th century India is also in the mainstream in the construction of concrete bridges at par with the developed countries. A century old Muvattupuzha bridge is the first major concrete bridge in India which is constructed across Muvattupuzha river located in Muvattupuzha in Ernakulum district of Kerala state was opened to traffic in 1914.Also the first pre stressed concrete railway bridge in the world was constructed near Siliguri in West Bengal. The first pre stressed concrete road bridge is across Palar river in Chengalpattu in Tamilnadu which was opened in the year 1952[1].

During these years the construction methodologies has been changed drastically. New technologies were introduced. Apart from railway over bridges and railway under bridges flyovers and interchanges are widely constructed. Even though the new technologies were introduced the cost effectiveness of the project or the cost minimization of the project is not yet considered in the right sense.

Fig- 1: Muvattupuzha Bridge

2. GENERAL CONSIDERATIONS

As a general rule the economical span is the span in which the cost of super structure equals the cost of substructure [2]. But this has certain limitations as the cost of substructure depends on many parameters including the type of foundation and soil properties. So the concept of economical span is not met with in most cases.

Nowadays pile foundations are preferred for almost all bridges. The overall cost of construction of bridge is directly proportional to the cost of piling works. The cost of piling work is proportional to the number of piles and the depth of pile. The number of piles depends on pile capacity which is related to the diameter of plies.

Another important aspect in design point of view is that the change in the dead load is more critical than that of live loads. This means that up to certain extent the live load will be more or less constant and the dead load of the superstructure will govern the loads to be transmitted to the substructure. So balancing the cost of substructure and the cost of superstructure should be essential in minimizing the overall construction cost of bridge works considering the stability, durability and other aspects.

3. FACTORS INFLUENCING COST OF CONSTRUCTION OF BRIDGES

There are several factors which influences the cost of construction of bridges. These general constituent members who contribute the cost of construction are

- Sub structure
- Super Structure

3.1 Sub Structure

The cost of substructure entirely depends on the soil parameters at the bridge location. If the piles are of end bearing type with minimum depth the construction cost will be minimum. On the other hand if the piles are of end bearing or friction type with considerable depth the cost will be on the high. In most cases the sub structure cost is predominant. This is mainly due to the improper number of piles allocated in a pile group. Due to this we cannot utilize the pile capacity at its maximum. This in turn increases the total number of piles to more than that required actually. Another thing which contributes to the higher overall construction cost is the usage of uneconomical pile diameter. This may be due to the non inclusion of the relevant details in the soil exploration report. So the comparison of cost by using different diameter piles is not worked out. In order to study the different options the pile capacity of different diameter of piles should be furnished in the soil exploration report. The higher percentage of reinforcement provided in piles and substructure is also a reason for the higher construction cost. So the reinforcements should provide to cater for the needs only. Also the sizes of pile cap, columns and pier heads also should be minimum. Otherwise the cost will shoot up.

3.2 Super Structure

For a constant width the cost of super structure is entirely depends on the span of the bridge. If the span is less the cost will be less and if span is more, the cost will also be more. The type of bridge like solid slab, voided slab, I girder and box girder also affects the construction costs. For effective spans up to 10 m the solid slabs will be economical. Table-1 shows the details of RCC T –Beam and slab superstructure MOST designed bridges for various spans [3]. Chart-1 shows the graph of the variation of span length to that of the dead weight of bridge.

Table- 1: Details of MOST RCC T-Beam Bridges

Sl. No.	Effective Span	Drawing No.	Qty. of Steel (T)	Qty.of Concrete (M^3)	Total Weight (KN)
1	24.0m	SD/210-217	32.86	215.45	5736
2	21.0m	SD/220-227	27.35	179.10	4816
3	18.0m	SD/230-237	22.87	139.74	3799
4	16.0m	SD/240-247	19.89	119.80	3273
5	14.0m	SD/250-257	17.18	102.22	2803
6	12.0m	SD/260-267	14.27	84.15	2320
7	10.0m	SD/270-277	11.41	67.75	1880

The graph of the variation of span length to that of the dead weight of bridge is shown in chart-1.\

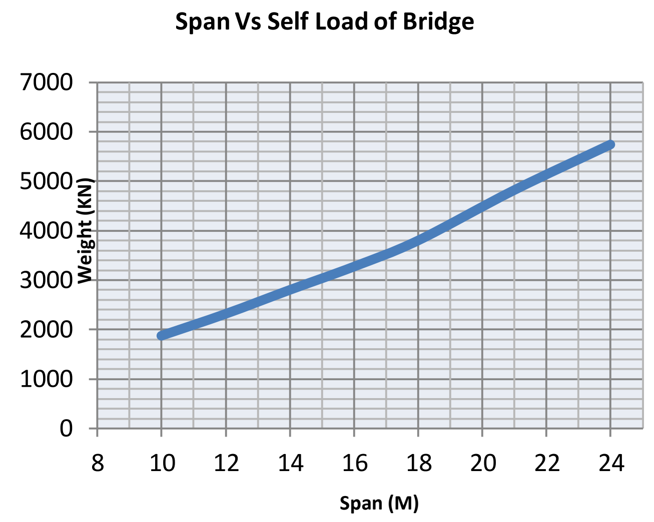

Chart- 1: Span vs. Self Load of Bridge

From this data it is evident that the dead weight of the bridge super structure is not following a linear variation. This point should be given due importance for minimizing the overall cost of construction.

4. DESIGN METHODOLOGY

Generally the design is based on the span which provides the minimum horizontal clearance for the particular purpose.

The same span is followed for the entire length. In most designs the full capacity of the pile is not utilized. When the depth of pile is more the overall cost in this regard is considerable.

In the optimum design we can utilize the pile capacity at its maximum. So it is very much important to conduct the soil exploration by a reliable agency. The pile capacity both vertical and horizontal should be handy for the design process. Also pile capacities of different diameters are necessary for comparison. The optimization is a trial and error process. To get a better insight in to the problem we can consider pile groups with 3, 4, 5 and 6 number piles in a group. The arrangements are shown in fig.-2 and fig.-3.

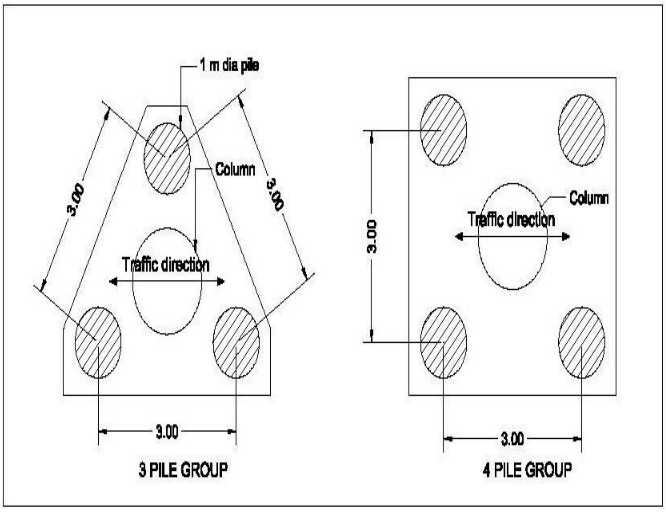

Fig -2: Pile Arrangement for 3 and 4 numbers Pile Group

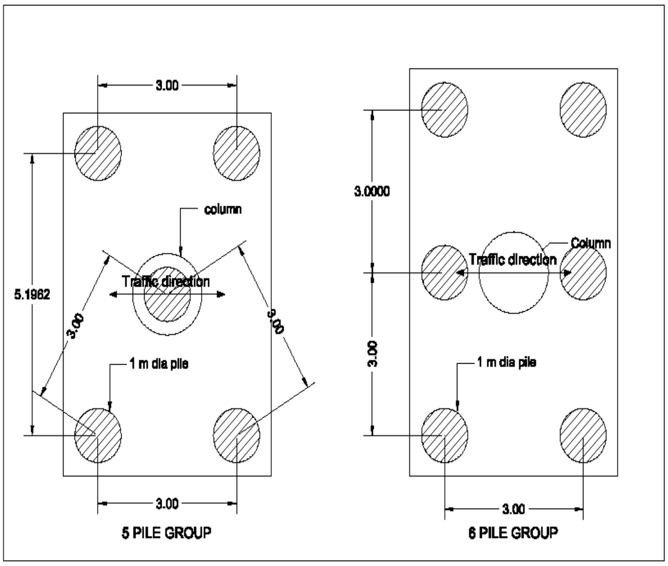

Fig -3: Pile Arrangement for 5 and 6 Numbers Pile Group

A typical comparison of maximum load on pile is shown in table- 2

Table- 2: Maximum Load on Piles

Sl. No.	Description	Effective Span			
		10 m	16m	21m	24m
1	Loading	70R	70R	70R	70R
2	Dead load(KN)	1880	3273	4816	5736
3	Pile diameter (mm)	1000	1000	1000	1000
4	No. of piles	3	4	5	6
5	Pile cap depth(M)	1.50	1.50	1.50	1.50
6	Pile cap area(M^2)	12.26	20.25	30.15	33.75
7	Max.load on pile(KN)	1503	1563	1704	1603

Now if the maximum allowable load on pile is 1603KN, we can find out the probable span for 3,4and 5 numbers pile group which will induce a maximum load of 1603KN on the pile group for the comparison of cost. By using SPSS software the relation between span length and self weight as per the MOST Designs is established as

S.L=11.274S2-0.118S3+885.267

where
S.L=Self Load in KN and
S=Span length in meters

The derived span lengths are 11.22m, 16.45m and 19.74m for 3, 4 and 5 number piles group respectively.

The Expression for the quantity of concrete and Quantity of steel is shown below

C=.409S2-.004S3+31.37 and
R.S=1.225S-1.025 where
C=Quantity of concrete in M^3,
R.S=Quantity of steel in Tonnes and
S=Span length in meters

The estimated quantities with a pile length of 30 m and Mild Steel Liner of 9m are shown in table -3.

Table -3: Estimated Quantities

Sl. No	Items	SPAN			
		11.22 m	16.45 m	19.74 m	24.00 m
1	Piles (M)	90.00	120.00	150.00	180.00
2	M.S.Liner (M)	27.00	27.00	27.00	27.00
3	Pile cap (M^3)	19.13	30.38	45.23	50.63
4	Column etc. (M^3)	16.98	21.16	23.79	27.20
5	Super structure concrete (M^3)	76.98	124.00	159.74	235.43
6	Super structure steel(T)	12.72	19.13	23.16	32.86
7	Hand rails foot path etc.(M)	23.64	34.10	40.68	49.20
8	Neoprene Bearings (cm^3)	33103	41262	46394	53040
9	Strip seal expansion	11.25	11.25	11.25	11.25

	joint(M)				
10	CC wearing coat(M^3)	6.65	9.59	11.44	13.84

The probable overall cost per meter length of bridge is shown in table -4.

Table 4: Overall Cost/M Length

Sl.No.	Span	Rate/m
1	11.22m	Rs.543580
2	16.45m	Rs.557410
3	19.74m	Rs.598212
4	24.00m	Rs.665081

Now if the pile capacity is 2060KN by using the same methodology, the cost per meter is as shown in table-5.

Table -5: Cost/M for 2060 KN capacity Piles

Sl.No.	Span	Rate/m
1	11.22m	Rs.543580
2	16.45m	Rs.493539
3	19.74m	Rs.541132
4	24.00m	Rs.625568

From the above it is evident that the cost of construction is very much related to the capacity of piles. Also the cost will be on the least with minimum number of piles in a group which utilizes its maximum capacity. When we utilize the pile capacity at its maximum we can reduce the construction cost to a great extent. This will be particularly significant when the pile length is more.

In the optimum design the pile capacity should be equal to the maximum load on pile for the corresponding span length.

From the above comparison it is also inferred that for the same pile if the pile capacity is more we can opt for increased span length which will be cost effective. Here the pile capacity for particular piles in a group is constant. So there arises the problem of optimizing the span length for the optimum cost. For the resolution we should study the different loads coming on the piles in a group.

$$\text{Max. Load on Pile} = \frac{D.L.\,of\ Sub\ Structure + Super\ Structure}{n} + \frac{L.L.\,of\ Super\ Structure}{n} + \frac{Unbalanced\ Moment\ due\ to\ D.L.\,and\ L.L.\ of\ Sub\ Structure\ and\ Super\ Structure}{z} + \text{Self Weight of unsupported length of Pile}$$

Where n=number of piles in a group

$$z = \Sigma\,(d_1^2 + d_2^2 + d_3^2 + \ldots)/d_i,$$

di=Distance from the c.g.of the pile cap to the centre of the concerned pile

The self weight of unsupported length of pile is constant for a group of piles. So in order to allocate maximum loads for the super structure for increasing the span we have to reduce other components.

As far as the load due to the unbalanced moments is concerned it depends on the distance of the pile centre to the c.g.of the group. For limiting this component the distance between the piles should be minimum

For limiting the dead load of substructure the pile cap size should be minimum. The sizes of columns, trestle head etc.should also are minimum for reducing the dead load of these structural components.

5. OPTIMIZATION PROCEDURE

Before starting the design works soil exploration report on sufficient number of bore holes should be available. The soil exploration report should contain the soil strata, probable founding level and the pile capacity both vertical and lateral for different diameter of piles say 800mm, 1000mm, 1200mm or 1500mm etc.

Details of columns, pier head sand pedestals for previously done similar work for different spans are useful for the preliminary assessment of the quantities of these items.

From the site level details fix the cut off level .Pile cap depth can be taken as 1.5D where D is the diameter of pile. The columns can be square or circular. Standard dimensions can be used.

The top level of the bridge can be fixed based on the requirement of vertical clearance etc.

As discussed earlier the least cost will be at minimum number of piles at a group. So we can try with say 3 numbers of 1 m diameter pile. Provide minimum dimensions for pile cap based on the codes followed. Now prepare a spread sheet for calculating the maximum load on pile using excel or any other software. Dead loads of superstructure columns, pier heads, and pedestals etc.can are assessed from the previous data as elaborated earlier. Live loads should be in accordance with the admissible codes. Try with a span of say 10m.If the maximum load on pile comes less than that of the pile capacity, we can try with a higher span length. By trial and error we can find out the span which will closely satisfy both the lateral and vertical load capacity of pile.

Similarly we can find out the spans for pile groups with different numbers of piles which gives the maximum utility of pile capacities. Now we have different spans which utilize different number of piles in each group. From this data we can calculate the construction cost per meter of bridges with different spans by using the rates prevailing in the locality. Make tabulation and compare the cost.

Further we can repeat the same procedure for using other diameter piles also. The overall comparison statement will guide for the right selection of span length for the construction of the bridge with optimized cost. Minor changes in the span lengths can be made in the end spans for accommodating the space limitations. Also when it requires more span length for a particular purpose such as a waterway or a road crossing, use the span length as appropriate for that particular portion only to limit the construction cost to a minimum.

After finalizing the span lengths do proceed for the detailed structural designs for the piles, sub structure and super structure. Here also do particular attention to limit the reinforcements as far as possible to effect the cost optimization.

6. CASE STUDY

We have already discussed the different possibilities of cost optimization in multi span bridges or Fly overs.Now we can go through a real practical situation where this type of optimization is implemented.

Fig -4: Bridge at Kollam

This is the case of the construction of bridge across T.S.canal which is popularly known as Iron Bridge because in pre independence days there exists an iron bridge and later it is replaced by a concrete bridge.

The proposed bridge is parallel to the existing bridge in the heart of Kollam city along the National Highway. The soil is very weak and exhibits negative skin friction also. In the original proposal there were 3 spans of 25.36 Meters in which one span is across the canal and the others are land spans on either side of the canal and approach roads to both sides. As per the original proposal 3 spans of 25.36M constructed already. Because of the very low bearing capacity of the soil, the approach road is replaced with approach spans.

Fig -5: Kollam Bridge top view

As per the new proposal the pile length is approximately 50 m and the Mild Steel liner requirement is up to 33m for 1m diameter piles. The safe load on 1 m diameter pile is 210T.In order to reduce the dead load Pre stressed concrete slab is proposed for the super structure. The various combinations of piles for different spans are studied for the maximum usage of the pile capacity. It is found that 11.56m PSC Slab is the most economical one. A comparison is shown in table-6

Table -6: Cost Comparison of Kollam Bridge.

Sl.No.	Description	Existing	Proposed
1	Span	25.36m	11.56m
2	Number of Spans	3	12
3	Type of bridge	RCC T-Beam	PSC Slab
4	Pile Diameter	1200mm	1000mm
5	Number of Piles in a group	8	3
6	Total Length	76.08m	138.72m
7	Total Cost	Rs.7,75,00,000	Rs.9,95,00,000
8	Cost/M	Rs.10,18,664	Rs.7,17,272

7. CONCLUSION

The advancement in the technologies reduced the time of construction of bridges substantially. But this will not reflect in the overall cost of construction. This may be due to the fact that the engineers in the bridge sector are least bothered about the optimization of design or the optimization of the cost. This should be changed. The general tendency of using type drawings for the super structure of bridges should be discouraged. Every project is unique in nature. So tailor-made solutions are necessary to impart overall cost reduction for the project. The bridge design engineers should do due importance to the optimization today itself not only for the cost reduction for the high economic efficiency but also for the saving of natural resources for the infrastructure developments for today and for the generations of tomorrow.

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