*Proceedings of the 2nd International Conference on Civil, Structural and Transportation Engineering (ICCSTE'16)*
*Ottawa, Canada – May 5 – 6, 2016*
*Paper No. 114*

# Effect on Economy on Successive Increase in the Span of Bridges

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***Abstract*** - In this present study an attempt is made to compare the cost of the superstructure of bridges for 20m and 25m span. Four types of the superstructures are used for the study purposes, namely; reinforced concrete T-beam, reinforced concrete I- beam, prestressed concrete I-beam and steel composite I-beam. For the analysis and design purposes, the loading standards of the Indian Road Congress (IRC) have been adopted. The study is done by calculating the cost associated with various stages of construction and service life and these are, the basic material cost, transportation cost, placement/launching cost, maintenance cost and the lifecycle cost. The effect of location of bridges on placement cost is also studied in detail. The repercussions of launching above the railway line and the indirect effect of cost in terms of block cost & speed restriction cost is also studied in details. In normal ground condition, reinforced concrete T-beam proves to be most economical for both the spans. Although in case of launching/placement above railway line, steel composite I-beam proves to be most economical option but when the Lifecycle cost is considered as a whole, prestressed concrete I-beam proves to be most economical for normal ground conditions and Composite Steel girder and RCC deck slab for launching above railway track. However reinforced concrete T-beam is most economical in construction over railway track but it is built cast in situ and launching process is not involved.

***Keywords*:** Railway block cost, Speed restriction cost, lifecycle cost, placement/launching cost, Reinforced concrete T-beam(RCCT-beam), reinforced concrete I- beam(RCC I-beam), prestressed concrete I-beam(PSC I-beam), steel composite I-beam.

## 1. Introduction

The India is witnessing the economic growth near to double digit and this growth is not feasible without the stimulus in the infrastructure sector. To sustain the growth of the economy at a high pace, the capital investment in infrastructure sector is the necessity. The transportation sector is the backbone of the economic development and bridges are the important and necessary parts of the transport infrastructure. The present study emphasizes on selection of bridge super-structure based on economy. There are mainly four types of bridge superstructures being used extensively in all over country; namely RCC T-beam, RCC I-beam, PSC I-beam and Steel composite. In first three types of the bridges, the main constituent material is concrete and in composite steel bridge, the girders are of steel and deck slab is of concrete. The design of all the options is done based on Indian Road Congress (IRC) codes. The constituent materials greatly affect the cost of the bridges, but other factors like supporting ground, location of bridge etc also play equally important role in overall economy of the bridge. An important aspect is location of bridge across the railway line, which greatly influence the cost of the bridge but barely gets attention of planners. This location specific cost component may not affect the cost of the bridge directly but has a huge cost burden on the existing railway company/department. The cost, which the railway company/department bears on account of detention of the trains and speed restriction due to the launching /placement processes of the girders, is also studied in detail.

## 2. Design Philosophy

The two superstructures having span of 21.96m and 26.96m with effective span of 20m and 25m respectively are analyzed by the grillage analysis for main girders along the longitudinal direction and slabs in the transverse direction. The deck slab is considered to be supported by four longitudinal girders with spacing of 2.65m in both the cases. The clear carriageway has been kept 7.5m with footpath on both sides. The total width of superstructure is kept 12.0m. The thickness of deck slab is kept uniform and same in both the cases. The sectional properties of superstructure in both the cases have been chosen on the basis of guiding formulas for various types of materials and spans and details are given in table No.1.

Table 1: Sectional properties of girders considered for comparison.

| No | Description | Unit | RCC-I Section | | RCC-T beam | | PSC-I Section | | Steel Composite | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span |
| 1 | Depth of deck slab | m | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| 2 | Web depth(excluding deck slab) | m | 1.80 | 2.00 | 2.25 | 2.30 | 1.56 | 1.85 | 1.35 | 1.67 |
| 3 | Top Flange width (at mid span) | m | 0.70 | 0.73 | 0.93 | 0.93 | 1.00 | 1.00 | 0.40 | 0.40 |
| 4 | Web width (at mid span) | m | 0.35 | 0.38 | 0.33 | 0.33 | 0.29 | 0.30 | 0.012 | 0.012 |
| 5 | Web width (at Support) | m | 0.70 | 0.73 | 0.63 | 0.63 | 0.80 | 0.80 | 0.012 | 0.012 |
| 6 | Bottom Flange width (at mid span) | m | 0.70 | 0.73 | 0.63 | 0.63 | 0.80 | 0.80 | 0.60 | 0.60 |

The grade of concrete for the reinforced concrete and PSC girder is kept M35 and M40 respectively. TMT Fe500 is used for the reinforcement in both the spans for all superstructure types. The results of analysis are shown in the graphical form to appreciate the variation in parameters (bending moments and shear forces), controlling the design of superstructure. The shape of shear force and bending moment curves in the Fig.1- 4 depicts that behavior of beams in both spans under live load and dead load is similar.

## 3. Methodology for the Cost Analysis:

The cost analysis of any structure include following five components in civil engineering generally:

i. Basic cost of the material involved in construction/Fabrication of the structure.
ii. Placement/ launching at the designated location of the structure.
iii. Finishing cost of the structure.
iv. Lifecycle cost of the structure.

### 3.1. Estimation and Costing Details

#### 3.1.1. Basic Material Cost

The basic material cost is calculated for all four options after the detailed quantity calculation for 20m and 25m span. The rates for the various components of the work are based on the Bridge works being executed by Indian Railways and other agencies in Northern India. The tender rates are updated based on WPI (Wholesale Price Index released by Reserve bank of India) for the current rates.

Table 2: Quantities of materials required for various Type of Super-Structures.

| No | Type of Superstructure | Qty of Material per Span (Including Deck Slab) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Concrete | | Reinforcement | | Shuttering | | Pre-Stressing Cable | | Structural Steel | |
| | Unit | Cum | | MT | | Sqm | | Kg. | | MT | |
| | Span | 20m | 25m | 20m | 25m | 20m | 25m | 20m | 25m | 20m | 25m |
| 1 | RCC T-beam | 159.0 | 203.0 | 29.0 | 38.0 | 680.0 | 960.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | RCC I-beam | 173.0 | 210.0 | 38.0 | 43.0 | 644.0 | 856.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | PSC I-Section | 162.0 | 202.0 | 19.5 | 29.00 | 563.0 | 791.0 | 3420 | 4700 | 0.0 | 0.0 |
| 4 | Composite Steel girder and RCC deck slab | 62.0 | 76.0 | 9.5 | 11.60 | 243.0 | 297.0 | 0.00 | 0.00 | 35.0 | 55.0 |

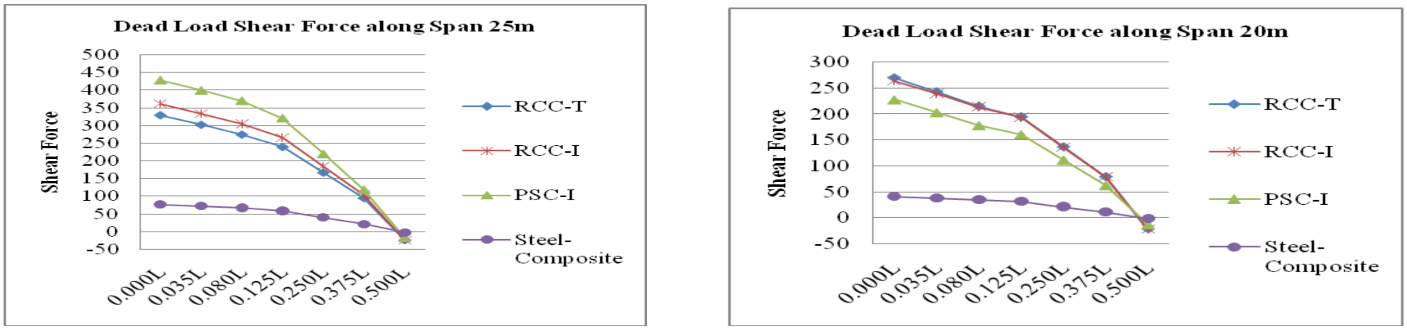


Fig. 1: Variation in Shear force along the span due to dead load.

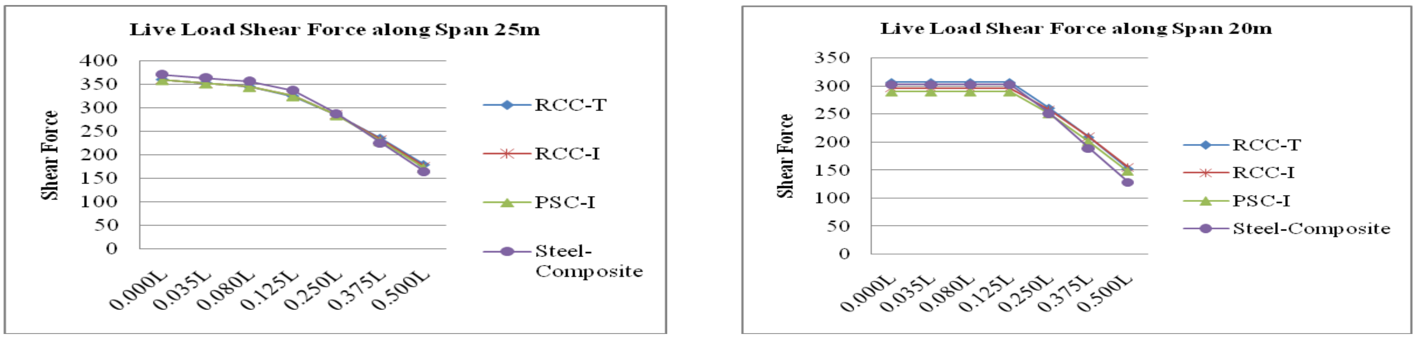


Fig. 2: Variation in Shear force along the span due to live load.

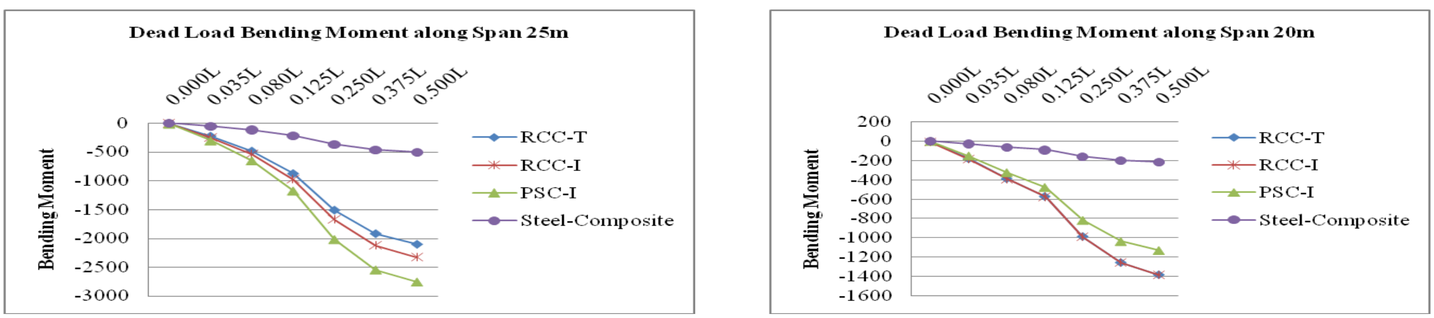


Fig. 3: Variation in Bending Moment along the span due to dead load

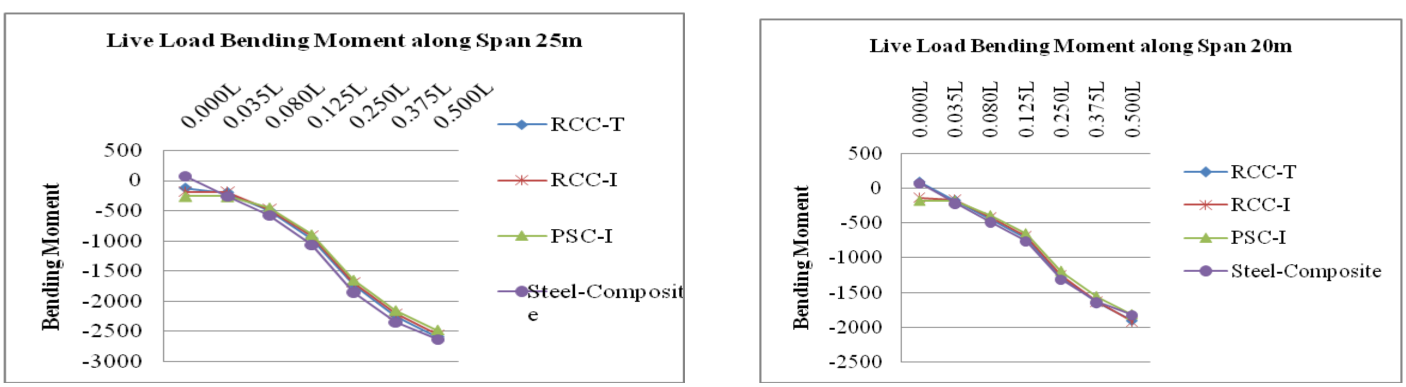


Fig. 4: Variation in Bending Moment along the span due to live load

Table 3: The Comparative construction/fabrication (materials) cost for 20m and 25m Span Bridge.

| No | Type of Superstructure | Construction/ Fabrication Cost (material cost) in INR | | Extra Cost in 25m Span in INR |
|---|---|---|---|---|
| | | 20m Spam | 25m Span | |
| 1 | RCC T-beam | 3341800 | 4313368 | 971568 |
| 2 | RCC- I-beam | 4041500 | 4728597 | 687097 |
| 3 | PSC I-Section | 3253000 | 4405566 | 1152566 |
| 4 | Composite Steel girder and RCC deck slab | 3797200 | 5497071 | 1699871 |

The above table No.3 clearly indicates that the construction/fabrication cost is minimum for PSC I-section and RCC T-beam for 20m and 25m span respectively. However, the difference in cost between RCC T-beam and PSC I-section is very small for both the spans.

### 3.1.2. Transportation Cost

The cost for transportation is not included in the present study. The transportation cost mainly depends on the setup of the contractor. It is difficult to make a comparison on basis of the transportation cost as the lead distance cannot be generalized for all the conditions. In case of steel fabrication, the Pre-Engineered beam structures are mostly being used, and for the PEB structures the yard cannot be set up on the designated location of the bridges. Mostly the PEB yard/facilities are situated at the fixed locations and the members are transported by road/rail to the required locations.

### 3.1.3. Placement/Launching Cost

The placement/launching of the girder is the process of final placement of the girders on the piers at required bridge location. The cost associated with the placement/launching is greatly affected by the prevailing site conditions. Greater the restriction in the free movement of the cranes greater the cost involved with the placement of the girder. Considering the type of ground condition which generally encountered can be broadly divided in the two categories; one is normal ground condition and another is above the railway line.

#### 3.1.3.1 Composite Cost for Placement/Launching in Normal Ground Condition

The work of placement/launching is generally done by using the hydraulic cranes. The important factor associated with the placement/launching is the weight of the girder/component being launched. More the weight of the girder, higher the crane capacity required for launching and consequently higher the placement/launching cost associated.

The RCC-T beam does not require any launching as it is constructed by caste-in-situ method. All other superstructure type under consideration requires the placement/launching of the spans by the crane. The launching cost is minimum for Composite Steel girder for both the spans, being light weight. Now, when we add the launching cost and basic material cost then interesting scenario develops.

Table 4: Total Composite Cost details Including Material cost & Launching cost in Normal Conditions.

| No | Type of Superstructure | Launching Cost by Crane(placement cost) in INR | | Construction/ Fabrication Cost (material cost) in INR | | Total Composite Cost in Normal Conditions in INR | | % Change in cost after adding Launching Cost | |
|---|---|---|---|---|---|---|---|---|---|
| | | 20m Span | 25m Span | 20m Span | 25m Span | 20m Span | 25m Span | 20m Span | 25m Span |
| 1 | RCC T-beam | NA | NA | 3341800 | 4313368 | 3341800 | 4313368 | 0 | 0 |
| 2 | RCC- I-beam | 300000 | 500000 | 4041500 | 4728597 | 4341500 | 5228597.2 | 7.4% | 10.6% |
| 3 | PSC I-Section | 300000 | 500000 | 3253000 | 4405566 | 3553000 | 4905566.3 | 9.2% | 11.3% |
| 4 | Composite Steel girder and RCC deck slab | 80000 | 100000 | 3797200 | 5497071 | 3877200 | 5597070.8 | 2.1% | 1.8% |

It is clear from the Table No.4; the effect of launching cost in 20m span as well as 25m span is minimum for the Composite Steel girder, which is 2.1% and 1.8 respectively. In terms of Total composite cost, RCC T-beam is the most economical option among the four types of superstructure considered. Whereas, in case of concrete beams, the launching cost is in the range of 10% of total cost of the span. In other three options, where launching is involved, total cost is lowest for PSC I-beam for both the spans.

The total cost of superstructure in case of normal ground conditions is calculated by adding the cost attributed to material quantities, launching cost and other allied activities.

#### 3.1.3.2 Composite Cost for Placement/Launching Above Railway Line

The work of placement/launching above the Railway Line is a very tedious job. It requires the extra safety measures for the Track and the Over Head Electric Traction lines. In Indian scenario, practice of taking "block" for the duration of placement/launching operation is followed. During the duration of block, the movement of passenger as well as freight trains is stopped in the section. Railway is virtually termed as lifeline of India and long duration blocks are not always feasible. Thus there is always restriction of the time for the placement/launching operations above the railway tracks. It is important to mention that this block duration adversely affect the finance of the already cash strapped Indian Railways. Suitably, an attempt made in this study to consider the financial implication for the railway for the block duration in the section.

Table 5: Total Composite Cost (material cost + launching cost) Above Railway Line (without traffic block and speed restriction cost).

| No | Type of Superstructure | Launching Cost by Crane(placement cost) in INR | | Construction/ Fabrication Cost (material cost) in INR | | Total Composite Cost Above Railway Line in INR | | % Change in cost after adding Launching Cost | |
|---|---|---|---|---|---|---|---|---|---|
| | | 20m Span | 25m Span | 20m Span | 25m Span | 20m Span | 25m Span | 20m Span | 25m Span |
| 1 | RCC T-beam | NA | NA | 3341800 | 4313368 | 3341800 | 4313368 | 0 | 0 |
| 2 | RCC- I-beam | 600000 | 1000000 | 4041500 | 4728597 | 4641500 | 5728597.2 | 14.8 | 21.1 |
| 3 | PSC I-Section | 600000 | 1000000 | 3253000 | 4405566 | 3853000 | 5405566.3 | 18.4 | 22.7 |
| 4 | Composite Steel girder and RCC deck slab | 160000 | 200000 | 3797200 | 5497071 | 3957200 | 5697070.8 | 4.2 | 3.6 |

It is clear from the table No. 5, the composite cost(material cost+ launching above railway line without block cost and speed restriction cost) is minimum for PSC I- section for both the spans. The RCC T-beam is constructed caste-in-situ at site and does not require any launching. The effect of block cost changes the overall economics of all superstructure types. For the caste-in-situ RCC T-beam, the cost of block may be not significant but the restriction on speed of trains imposed during the entire construction period badly affects the finance. This study also attempts to quantify the effect of Speed restriction as well as Block cost on all four types of superstructure.

The railway traffic block cost varies with the number of trains running in the section. For the present study the cost of block per hour for trains varying from 20 to 80 in a section per day is calculated. To quantify the cost associated with the speed restrictions, the speed restriction of 20 Kmph in a stretch of 100 meters has also been calculated. The continuous speed restriction for 15 days is kept for the casting of the Deck Slab of the bridge. The cost of launching/placement, traffic block and speed restriction is quantified for the all four types of superstructure and it is clear from the table No. 6 that, it is minimum for the RCC T-beam and Composite steel girder with minor difference of Rs. 1 lakh for 20m span and Rs. 2 lakh for 25m span for frequency of 20 trains per day. This pattern is same for the all the combinations of number of trains considered for the study and increases with increase in the frequency of trains in that particular section.

Table 6: Cost details of Placement including Launching above Railway Line, Traffic block and Speed Restriction Cost (in lakhs of INR).

| No. | Super-structure Type | Block Duration | | Speed restriction Duration | 20 Trains per day | | 35 Trains per day | | 50 Trains per day | | 65 Trains per day | | 80 Trains per day | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20m span | 25m span | | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span |
| 1 | RCC- T Beam | 2 | 2.5 | 15 | 65 | 75 | 106 | 124 | 147 | 172 | 189 | 220 | 230 | 269 |
| 2 | RCC- I section | 3 | 3.5 | 15 | 91 | 106 | 112 | 169 | 203 | 231 | 258 | 294 | 314 | 357 |
| 3 | PSC -I Section | 3 | 3.5 | 15 | 91 | 106 | 112 | 169 | 203 | 231 | 258 | 294 | 314 | 357 |
| 4 | Composite Steel girder and RCC deck slab | 2 | 2.5 | 15 | 66 | 77 | 108 | 126 | 149 | 174 | 190 | 222 | 231 | 271 |

Table 7: Total Composite Cost Including Fabrication/Construction Cost, Launching cost Above Railway Line, Traffic block and Speed Restriction Cost(in Lakhs of INR).

| No. | Super-structure Type | 20 Trains per day | | 35 Trains per day | | 50 Trains per day | | 65 Trains per day | | 80 Trains per day | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span | 20m span | 25m span |
| 1 | RCC- T Beam | 98 | 118 | 139 | 167 | 181 | 215 | 222 | 264 | 263 | 312 |
| 2 | RCC- I section | 132 | 153 | 152 | 216 | 243 | 279 | 299 | 342 | 354 | 404 |
| 3 | PSC -I Section | 124 | 150 | 145 | 213 | 235 | 275 | 291 | 338 | 347 | 401 |
| 4 | Composite Steel girder and RCC deck slab | 104 | 132 | 146 | 181 | 187 | 229 | 228 | 277 | 269 | 326 |

It is clear from the table no 7, that RCC T-beam is the most economical option for the locations where the bridge is being constructed above railway line. It is important to mention here that the RCC T-beam is constructed caste-in-situ and does not require launching/placement of the span. Among other three options where the launching by hydraulic crane is involved, Composite steel girder is the most economical.

### 3.1.4. Finishing Cost

The Reinforced concrete construction work in case of bridges or any other structure is generally does not require any finishing work. The sides of the crash barrier in case of roads are painted as per the type of usage and the cost mainly associated with the cost of the road finishing work. However in case of steel structure the cost of primer and painting is part of finishing work and are necessarily required for the completion of the work. It is important to mention that the rates adopted for the Composite steel girder includes priming coat and finishing coat of paints.

### 3.1.5. Lifecycle Cost

The lifecycle cost in general terms means the cost associated with the complete design life of any structure. The lifecycle cost in case of Bridges includes the various cost components. The Lifecycle cost analysis is a tool to help structural engineers in making investment decisions. A bridge lifecycle cost model can be expressed as follows;

$$LCC = DC + CC + MC + RC + UC + SV \tag{1}$$

Where,
LCC = life cycle cost, DC = design cost, CC = construction cost, MC = maintenance cost, RC = rehabilitation cost, UC = user cost, and SV = salvage value.

However in the present study, user cost (UC=0) as the construction of bridge is considered to be in green field conditions. Lifecycle cost is expressed as equivalent present worth of cost. The commonly used criterion for selecting or ranking alternative proposals is the net present value method. For calculating the net present value, following assumptions have been made:

- The design life of bridge is considered to be 100 years.
- The maintenance cost is taken as 0.05% of the capital cost for periodic cycle of 1 year.
- The inspection cost is taken as 0.15% of the capital cost for periodic cycle of 2 year.
- The deck overlay replacement cost is taken as 10% of the capital cost for periodic cycle of 20 year.
- The painting frequency, in case of steel bridge; is taken for periodic cycle of 8 year.
- The demolition cost at the end of service life of 100 years is taken as 10% of the capital cost.
- The salvage value in case of steel bridge is taken as 2% of the capital cost at the end of service life o 100 years.

Table 8: Lifecycle cost comparison for various type of superstructure for Normal ground conditions as well as above Railway Line.

| No | Type of Superstructure | Total Composite Lifecycle cost in Normal Ground Condition | | Total Composite Lifecycle cost Above Railway Line for 20 Trains per day | | Total Composite Lifecycle cost Above Railway Line for 50 Trains per day | |
|---|---|---|---|---|---|---|---|
| | | 20m Span | 25m Span | 20m Span | 25m Span | 20m Span | 25m Span |
| 1 | RCC T-beam | 35.03 | 45.22 | 99.61 | 120.08 | 182.61 | 217.08 |
| 2 | RCC- I-beam | 45.37 | 54.57 | 133.95 | 155.28 | 244.95 | 281.28 |
| 3 | PSC I-Section | 37.10 | 51.18 | 125.57 | 152.13 | 236.57 | 277.13 |
| 4 | Composite Steel girder and RCC deck slab | 41.45 | 59.88 | 106.68 | 135.91 | 189.68 | 232.91 |

## 4. Conclusion

The results of the study are evaluated for two different effective spans of 20m and 25m by considering various support conditions, constituent materials, casting/fabrication methodologies etc. to reach at best economical option including the lifecycle cost.

### 4.1. Basic Material Cost

From Table 3, among the four options of superstructure, for 25m spans; RCC T-Beam and for 20m span, PSC I section proves to be most economical solution considering the material cost only. The second best option is RCC-T beam for 20m span and PSC I section for 25m span. However, difference in cost in both options of RCC T-beam and PSC I-section is very small.

### 4.2. Placement/Launching Cost

The placement/launching of girder is studied for two types of site condition, one is in normal condition and another in case of placement/launching above railway line.

#### 4.2.1. In Normal Ground Condition

The launching/placement cost directly depends on the weight of the member.The Composite steel girder is having the minimum weight compared to all other superstructure types and involves minimum cost in launching/placement. It is important to mention that RCC T-beam is cast-in-situ and does not require any launching/placement.

Table 4; clearly indicate that the total composite cost of superstructure in normal conditions (launching cost and material cost) is minimum for RCC T-beam for both spans. However, among other three options where launching is involved, PSC I-section is most economical for both spans.

#### 4.2.2. Placement/launching Above Railway Line

The launching above the railway line mainly consists of two cost components. One cost component is attributed to the launching/placement operations due to restriction in term of space and time and another cost component is attributed to the indirect cost implication on the Railways in terms of Speed restriction on movement of trains and the block periods.

Table 5, clearly indicates that PSC I-section remains most economical for both the spans when only the material cost and launching cost is considered. Here RCC T-beam is not considered in the category of launching.

Table 7, when we combined the total cost including material cost, cost of lunching, block cost and the cost of speed restriction, composite steel girder becomes the most economical for both the spans. This is due to the fact that the composite steel girder is the lightest among all the other three options used for the study and RCC T-beam does not requires any launching/placement being caste-in-situ. But it is pertinent to mention that among all the four options, RCC T-beam is most economical option for construction.

The effect of cost of placement of span including launching cost, traffic block cost and speed restriction cost is more than 60% in the total cost superstructure.

### 4.3. Lifecycle Cost

The lifecycle cost is an important factor which facilitates the selection as well as optimization of resources for various types of superstructures. On Considering the Lifecycle cost as per table 8, the lifecycle cost is lowest for PSC I-section in Normal ground conditions and in case of Launching over Railway line, Composite steel girder with RCC deck slab proves to be most economical choice. When the Caste-in-situ RCC T-beam is also considered with the other three options, it proves to be best economical choice among all the four options for both the spans.

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