

Study on the Semi-Integral Bridge by Analysis of the Bridge by Changing the Parameters

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ABSTRACT: Bridge construction today has achieved a worldwide level of importance. Bridges are the key elements in any road network and use of pre-stress girder type bridges gaining popularity in bridge engineering fraternity because of its better stability, serviceability, economy, durability, aesthetic appearance and structural efficiency. Normally the type of construction used is reinforced concrete construction, steel construction or steel composite construction. When the span is high reinforced concrete construction is uneconomical due to increase in depth of span. Prestressed member, which are free from tensile stress under working loads, the cross section is more efficiently utilized than reinforced concrete section. Prestressed concrete is used for long span bridges above span length of 10m. Conventionally in Bridge analysis, the Super-structure and Substructure are analyzed separately. The Super-structure is usually a grid consisting of main girders, transverse diaphragms and deck slab. The deck slab is discretized into a grid of line elements. The supports of the main girders are pinned. The super-structure is analyzed for un-factored Gravity loads and Moving vehicular loads as per IRC: 6-2014 and as per IRC: 18-2000. The work discusses about the analysis and design of the semi-integral bridge. This work also discuss about on the choosing the economic section for the substructure by changing the parameters of substructure.

KEYWORDS: Prestressed concrete girder, post tensioning, moving load analysis, MIDAS, point spring.

LINRODUCTION

A bridge is a structure built to span a physical obstacle, such as a body of water, valley, or road, without closing the way underneath. It is constructed for the purpose of providing passage over the obstacle, usually something that can be detrimental to cross otherwise. There are many different designs that each serve a particular purpose and apply to different situations. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and the funds available to build it. Prestressed concrete is a form of concrete used in construction. It is substantially "prestressed" (compressed) during its fabrication, in a manner that strengthens it against tensile forces which will exist when in service. Prestressed concrete is used in a wide range of building and civil structures where its improved performance can allow for longer spans, reduced structural thicknesses, and material savings compared with simple reinforced concrete. Typical applications include high-rise buildings, residential slabs, foundation systems, bridge and dam structures, silos and tanks, industrial pavements and nuclear containment structures. Concrete is the most popular structural material for bridges, and prestressed concrete is frequently adopted. There are many types of bridges. Some of them are, Short span bridge, Medium span bridge, Long span bridge and Cable suspension bridge.

Bridge construction today has achieved a worldwide level of importance. Bridges are the key elements in any road network and use of pre-stress girder type bridges gaining popularity in bridge engineering fraternity because of its better stability, serviceability, economy, durability, aesthetic appearance and structural efficiency. There are semi-integral, integral and simply supported bridges.

Normally the common support conditions used in the bridges are simply supported which has expansion joints on end of each spans and for the integral type there will not be any expansion joints and are connected by an integral diaphragm. For the semi integral type the expansion joints are provided only in the abutments. Due to the expansion joints in the bridges there will be an increase in the deflection while comparing the integral bridge. The study is based on changing the parameters on the substructure and comparing the moments, shear force and other results from it.

II. STUDY OF A SEMI INTEGRAL BRIDGE

The Deck width is 10m to cater for two lane carriage way with footpath of 1.5m wide. The span arrangement adopted is continuous spans of 3 x 30.0m + 1 x 25.0 m + 1 x 30.0m. The structural system adopted is integral solution with end span with bearing at Abutments A1 and at A2 to avoid expansion joint for smooth travel experience. The superstructure consists of 6 precast post-tensioned girders with cast in-situ slab, carrying a 10m wide deck slab (200mm thick). The superstructure is monolithically connected to the pier forming beam column joint. In this proposed work the main objective is to change the parameters of substructure and to find the economical design.

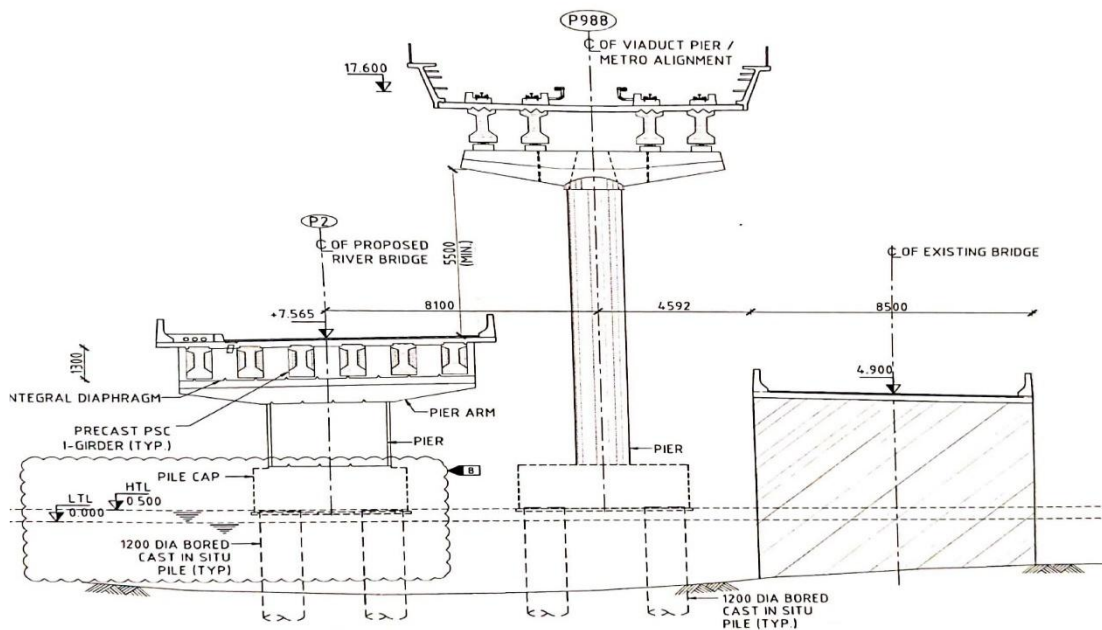


Figure 2.1 - Elevation of the bridge

Precast concrete is a method of construction that encourages quick construction of a structure utilizing sections that are manufactured off-site and afterward transported on site. In General, for a bridge, precast prestressed concept is employed for girders. When the deck is poured, the structure becomes composite, limiting deflections due to working loads.

Since precast girders require minimal false work, they are a favoured, where speed of development, negligible traffic disturbance, as well as natural effect is required. Precast girders utilize high performance concrete for quality, toughness, and additionally constructability and will in general be increasingly efficient and aggressive when critical repeatability exists on work (i.e., economy of scale).

The main objective of using prestressing is to produce minimal tension in the concrete under working loads and also to have less service load stress than the cracking strength of concrete throughout the cross section. Hence, steel is subjected to constant tension which keeps concrete will be under compression which makes both steel and concrete are used to maximum efficiency. Generally, in prestressed beams, steel strands are stretched, i.e., tensile force is applied to counteract the working loads. In this regard, two types of prestressing are used. They are pre-tensioning and post-tensioning.

Precast girders are prestressed to produce a uniform stress distribution along the section due to service loads which reduces the flexural cracking. For efficiency in the sections, the girders already have pre-compressed tensile zones at the bottom part of the girder at mid-span where compression is induced to counteract tension for dead loads and superimposed dead loads due to deck slab, crash barrier, wearing course, and live loads due to vehicles of different class as per IRC 6-2016. To achieve this, precast girders employ prestressing strands that are stressed before the concrete hardens which is called as pre-tensioning. This is quite different to post-tensioning girders, in which the

tendons are stressed after the concrete hardens. However, precast girders may also be pretensioned, then post-tensioned, and are sometimes spliced together to form a single span or continuous superstructure.

Pre-tensioning requires strong, stable end-anchorage beds between which the tendons are stretched. This casting bed which may be many times the length of the concrete element being fabricated. This allows number of elements to be constructed in the one pre-tensioning operation, allowing significant productivity benefits and economies of scale to be realized for this method of construction. On the other hand, in post-tensioning, once the concrete has been cast and set, the tendons are stressed by pulling the tendon ends through the anchorages while pressing against the concrete. The large forces required for tensioning the tendons result in a significant permanent compression being applied to the concrete.

Post-tensioning involves casting the tendon ducts into the concrete before any tensioning occurs allows them to be readily profiled to any desired shape including incorporating suitable curvature. When the tendons are tensioned, this profiling result in reaction forces being imparted onto the hardened concrete, and these can be beneficially used to counteract the service loads. Post-tensioning involves two other methods, i.e., bonded and unbonded post-tensioning. These are widely used system and however the choice of system to adopt is often governed by regional preferences, contractor experience, or the availability of alternative systems meeting the structural strength and serviceability requirements of the designer. Posttension box girder superstructures are commonly used due to their comparatively less costs, their performance throughout the life of the structure, and contractor's experience with the type of the structure. Posttensioning also allows for thinner superstructures. A continuous superstructure increases the stiffness of the bridge frame in the longitudinal direction and gives the designer the option to fix the columns to the superstructure, reducing foundation costs.



Figure 2.2 Pre-stressed I-girders

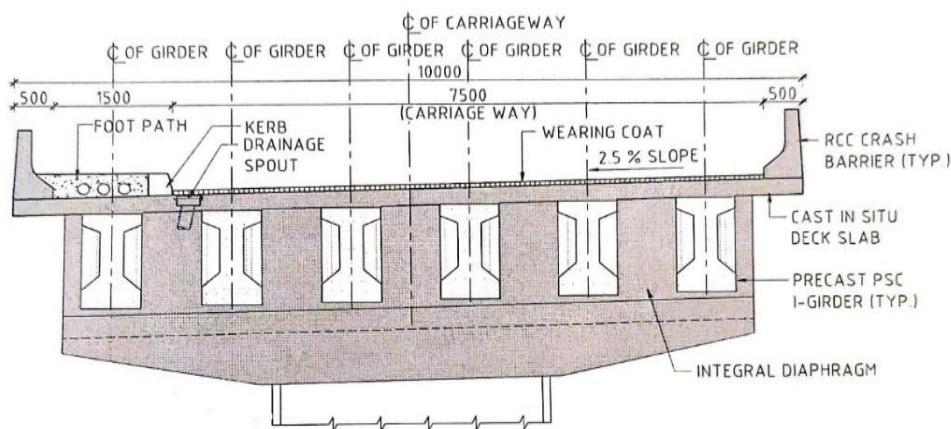


Figure 2.3 General arrangement of PSC-I girder

Analysis of the superstructure and substructure are carried out for dead loads, super-imposed loads, wind loads and moving loads. For vehicle load the class 70R and class A loadings and the load combinations for ultimate limit state

and service limit state are assigned to the model as per IRC: 6-2017.

Table B.3 Partial Safety Factor for Verification of Serviceability Limit State

Loads (1)	Rare Combination (2)	Frequent Combination (3)	Quasi- permanent Combination (4)
1. Permanent Loads:			
1.1 Dead Load, Snow load if present, SIDL except surfacing	1.0	1.0	1.0
1.2 surfacing			
a) Adding to the effect of variable loads	1.2	1.2	1.2
b) Relieving the effect of variable loads	1.0	1.0	1.0
1.3 Earth Pressure	1.0	1.0	1.0
1.4 Prestress and Secondary Effect of prestress	(Refer Note 4)		
1.5 Shrinkage and Creep Effect	1.0	1.0	1.0
2. Settlement Effects			
a) Adding to the permanent loads	1.0	1.0	1.0
b) Opposing the permanent loads	0	0	0
3. Variable Loads:			
3.1 Carriageway load and associated loads (braking, tractive and centrifugal forces) and footway live load			
a) Leading Load	1.0	0.75	-
b) Accompanying Load	0.75	0.2	0
3.2 Thermal Load			
a) Leading Load	1.0	0.60	-
b) Accompanying Load	0.60	0.50	0.5
3.3 Wind Load			
a) Leading Load	1.0	0.60	-
b) Accompanying Load	0.60	0.50	0
3.4 Live Load surcharge as accompanying load	0.80	0	0
4. Hydraulic Loads (Accompanying loads) :			
4.1 Water Current	1.0	1.0	-
4.2 Wave Pressure	1.0	1.0	-
4.3 Buoyancy	0.15	0.15	0.15

Figure 2.4 Load combination for design of superstructure and add substructure

Results of various load combinations are checked and the maximum values of the load combinations are taken for the calculations of reinforcements and the necessary checks. Superstructure consists of cast-in-situ deck slab with a width of 10m to cater 2 lane carriageways and precast PSC girder having total depth of 1500mm. The superstructure is connected to abutment by means of the expansion joint.

The grade of concrete used for deck slab, pile cap, PSC girder, diaphragm was M50 and M40 was used for pier, pier arm, pile and abutment cap. The modulus of elasticity of concrete (E_{cm}) for M40 and M50 are 33000Mpa and 35000Mpa. The grade of reinforcement used is Fe500D. The unit weight of reinforcement is taken as 7.85kN/m³. The Modulus of elasticity considered is 2×10^5 Mpa. Prestressing steel will be conforming to IS: 14268, class- II 7 ply strand of low relaxation type with diameter of 15.24mm.

III. ANALYSIS AND DESIGN OF A SEMI-INTEGRAL BRIDGE

Superstructure is modelled for 6 nos. of PSC I girders for each span and a deck slab thickness of 0.2m for a total span of 145m. The total width of the deck is 10m. The longitudinal and transverse loading are applied as per IRC: 6-2017. For each span the ends are connected by means of an integral diaphragm and at the abutments it is connected by means of an expansion joint. The site is near the coastline and so the exposure condition is taken as “Severe Exposure” as per table 14.1 of IRC: 112-2011 severe condition is assumed as the relative humidity is greater than 70%.

The superstructure is supported by four piers which are connected to the pile. The size of the pier is 1.2m x 3.6m designed as per IRC guidelines. The pier are supported by a 1.5m and 1.2m diameter piles of 4 and 6 groups. The water current forces for piles are calculated as per IRC guidelines.

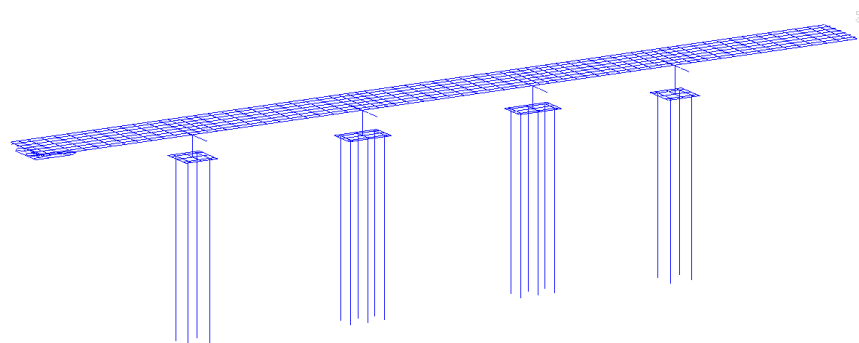


Figure 3.1 Grillage model of the bridge

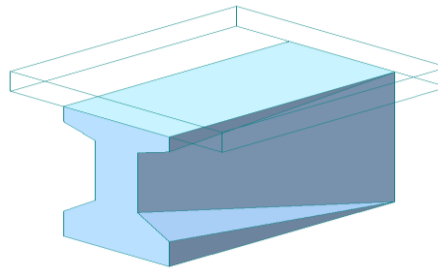


Figure 3.2 Varying section of the I-Girder

Section properties are calculated for the girders and assigned to respected beams modelled in MIDAS. Properties are calculated for mid-section and support section. Properties for varying section is approximately taken as average of mid-section and support section.

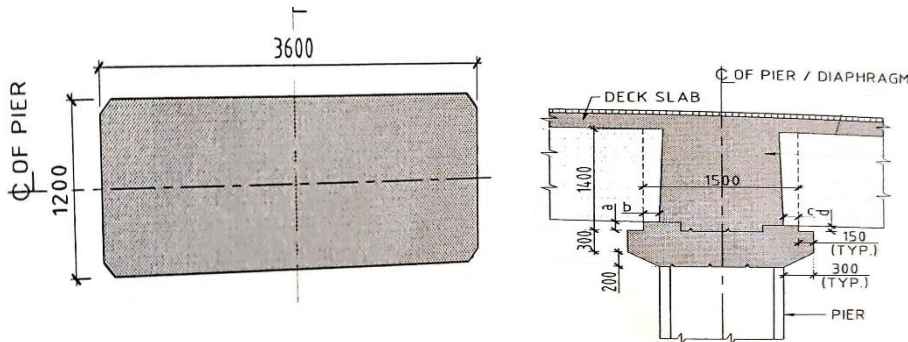


Figure 3.3 Sectional view of Pier and pier arm

The substructure consist of four piers each of different heights and the loads are calculated separately for each pier. For the analysis of the pier the moving load has to be changed to static loads and has to be applied on the deck slab. For that we have to find the maximum reactions in pier due to different moving load cases and should be applied as static loads. The other force applied on the piers are the wind load. After analyzing the structure for the above loads we could calculate the area of tension reinforcement and the necessary checks has to be done.

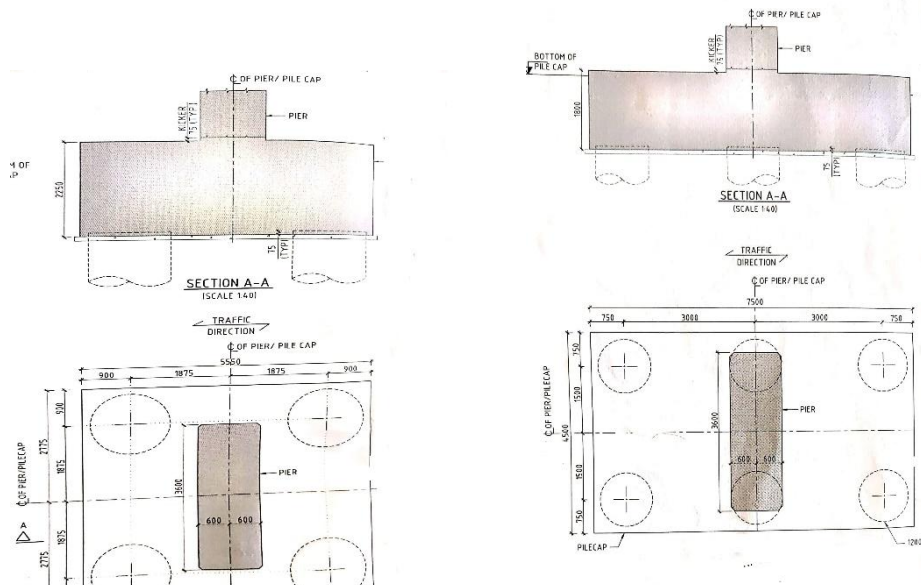


Figure 3.4 Pile and pile cap of the bridge

The substructure consist of four pile groups in which it has two groups of four pile of 1.5m diameter and two group of six piles of 1.2m diameter. The forces acting on the piles other than vertical forces the horizontal forces acting on the piles are water current forces and earth pressure. The seismic analysis of the piles are different, since the response reduction factor is different for piles and for the super structure as per IRC: 6-2017. The piles are analyzed for load combination of both ULS and SLS loads cases

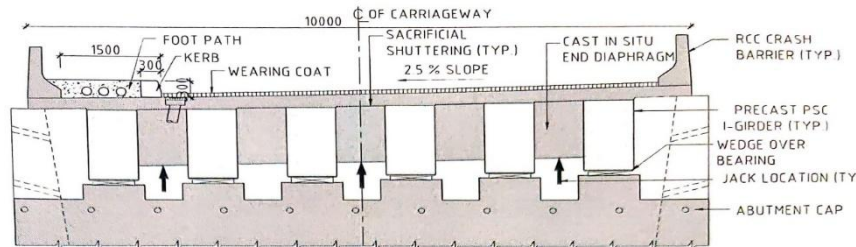


Figure 3.5 Sectional view of abutment

The design loads for the bridge has been considered in accordance with IRC 6-2017 so as to sustain the most critical combinations of various loads, forces and stresses.

The superstructure consists of prestress girder and deck slab. Hence, design involves two parts, i.e., Prestress design and secondary reinforcement design. This composite action of the structure is design is carried out after the structure results safe for the flexural stresses due to Bending moments for various load conditions and load combinations. Also, ULS and SLS checks due to bending moments, shear force and to rnsions are carried out for which the secondary reinforcements are designed.

Prestress design is done for precast girders which involves various steps as follows:

- Deciding the number of strands and cables
- Preparing the layout of cables
- Calculation of cable losses due to immediate and permanent losses (Friction, Elastic shortening, Anchorage slip, Shrinkage and Creep).
- Checking the flexural stresses followed by ULS and SLS checks for design of secondary reinforcements.

The cable profile adopted generally for these cables are parabolic curves. Cable duct outer diameter considered is 85mm and the sheathing thickness may be 2.3 ± 0.3 mm. The bars used are high strength deformed bars Fe500D conforming to IS: 1786-1985. The jacking force per cable shall be equal to 78.3% of UTS. Minimum clear cover to post tensioned ducts is 75 mm.

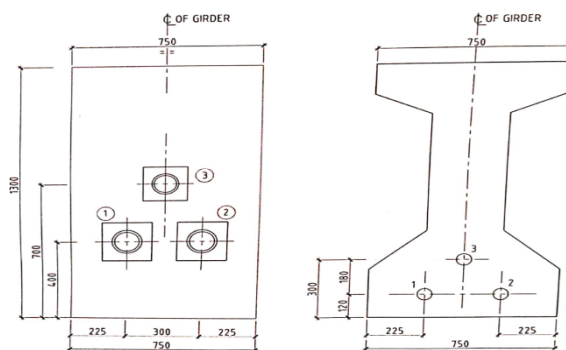


Figure 3.6 Prestressing cable profile

The sequence of stressing should be done in the following order - 3, 2, and 1 as shown in the above figure. In case if the elongation is reached and the jacking force is not reached, stressing shall be continued up to 5% excess of prescribed elongation. Extension shall be rechecked at 24 hours after anchoring to observe the slow slippage. Initial slackness in the Prestressing cable shall be removed by applying small tension. Correction shall be done as per clause 13.2.1.2 of IS: 1343-2012. Grouting shall be done 24 hours after stressing the strands. Extra length of the stand shall be cut after the grouting.

Losses of prestress is calculated as per IRC 112 provisions. Properties of sections are calculated and respective losses are calculated. For I girder, permissible stresses for losses are estimated at 7 days, 21 days and end of life (total life of the structure is considered as 100 years as per IRC 5). For box girder, losses are estimated for 7 days, 14 days and end of life.

After estimating stresses for the composite action of girder and deck slab, the superstructure is designed for reinforcements as per the provisions provided in IRC 112. RC detailing for Girders, Anchor blocks, deck slab are tabulated below. Anchor blocks are designed for maximum bursting force and equilibrium reinforcements and area of steel (HTS) for strands used in the girder are designed as per the guidelines.

Diaphragms are designed for jacking case and service case for Precast or prestressed girders to improve the stiffening of girders and reducing the girder deflections. Usually, diaphragms are provided to keep the girders together. And also improving the load distributions. It also, helps in reducing the accidental overturning of girders during construction. However, bearing pads are designed to carry the loads and transfer to the substructure and allow horizontal movement of the bridge superstructure. But the combine effect of diaphragms and bearing pads increase the total performance of the bridge for deformations and service load conditions.

For analysis of substructure, superstructure was analyzed for various dead loads, permanent loads and vehicle load conditions. Load combinations are adopted as per IRC 6-2017. The model has been analyzed for five spans superstructure for governing live load case. For pier, loads due to dead weight, permanent loads, bearing resistance, water current, seismic forces, buoyancy, wind loads are considered for HFL and LWL conditions for SLS and ULS conditions. Whereas for abutments, earth pressure is calculated in addition to the above mentioned loads.

The reactions from analysis is taken for further design of substructure using developed excel sheets and corresponding stresses, ULS and SLS criteria are checked. From which maximum axial force, transverse moment and longitudinal moments are calculated for different load conditions and load combinations.

Loads were calculated at pier top level and bottom level; the reactions are then taken to design the suitable foundation. Stresses for pier were calculated for pier and abutments and were found to be within the permissible limits. Requirement for shear reinforcement was checked and suitable reinforcement was provided as per the standard provisions

Also, detailing for surface reinforcement, shear reinforcement and ductile detailing were done as per IRC Standard provisions. The final section of I girder superstructure is shown in the following figure which was resulted from the detailed analysis and design of the structure.

IV. CASE STUDIES

4.1 CASE STUDY-1 POINT SPRING SUPPORT FOR PILES

The piles are provided only where the soil condition is worse or when the structure is large. In case of piles founded on hard stratum and deriving their capacity mainly from end-bearing the minimum spacing shall be 2.5 times the diameter of the circumscribing circle corresponding to the cross-section of the pile shaft. In case of piles resting on rock, the spacing of two times the said diameter may be adopted. Piles deriving their load-carrying capacity mainly from friction shall be spaced sufficiently apart to ensure that the zones of soils from which the piles derive their support do not overlap to such an extent that their bearing values are reduced. Generally the spacing in such cases shall not be less than 3 times the diameter of the shaft.

Normally the piles would be fixed at the top of pile cap, but by providing the point spring supports the bottom of the pile become fixed instead of the top. The point spring supports provides stiffness to the pile. It also helps in the distribution of loads to the piles. In case if there is no point spring supports provided in the piles the load carried by the piles are less compared to the pier and pile cap. There will not be equal distribution of loads since the fixity is provided

at the top. While if the point spring supports are provided, a stiffness is induced in the piles and the fixity in at the bottom of the piles providing more efficient load distribution. It also helps in the reduction of the reinforcement.

4.2 CASE STUDY-2 CHANGING THE SHAPE OF THE PIERS

The pier on the structure are basically designed as columns. The design is based as per IRC: 112-2011. At first we have to check if the pier are subjected to uniaxial or biaxial bending and then the section properties are calculated. The ductile detailing is provided as per IRC:112-2011.

The shape of the pier is an important part of substructure because by changing the shape of the pier we could transfer the moment and shear force more effectively. The model was analyzed for rectangular pier and circular pier. Form the results the rectangular pier was more effective than circular pier. The longitudinal moment was more effectively distributed to the piles comparing to the circular pier. The percentage of reinforcement was also reduced in rectangular pier than circular pier.

4.3 CASE STUDY-3 CHANGING THE PILE GROUPS

In order to determine the load-carrying capacity of a group of piles a number of efficiency equations are in use. However, it is difficult to establish the accuracy of these efficiency equations as the behavior of pile group is dependent on many complex factors. It is desirable to consider each case separately on its own merits. The load-carrying capacity of a pile group may be equal to or less than the load-carrying capacity of individual piles multiplied by the number of piles in the group. The former holds true in case of friction piles, cast into progressively stiffer materials or in end-bearing piles.

In case of a structure supported on single piles/ group of piles resulting in large variation in the number of piles from column-to-column it may result in large differential settlement. Such differential settlement should be either catered for in the structural design or it may be suitably reduced by judicious choice of variations in the actual pile loading. For example, a single pile cap may be loaded to a level higher than that of the pile in a group in order to achieve reduced differential settlement between two adjacent pile caps supported on a number of piles. The bridge had a 4 pile of 1.5m diameter of two group and 6 piles of 1.2m diameter of two groups. Comparing it with all 4 pile group of 1.5m diameter. Form the analysed results, the first case had efficient load distribution and a reduced reinforcement ratio compared to the all 4 pile group.

V. CONCLUSION

In this study a semi integral bridge was analysed for change in different parameters in the substructure. The results obtained are,

1. By adding the point spring supports to the pile there is a change in the load transfer to the pile and the stiffness of the pile is also increased due to the provision of the spring in the piles.
2. While changing the shape of the pier there is a significant change in the percentage of reinforcement and the load taken by the pier also differs.
3. The change in the arrangement of piles also results in change in the reinforcement ratio.

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