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# Determining the Relationship between Depth of Foundation and Loading on Bridge Using Linear Regression

**Pradyut Anand[1]**

[1]Civil Engineering, Birla Institute of Technology Mesra, HOUSE NO 396 B ROAD NO 4C, RANCHI, 834002, JHARK- HAND, India. Tel.: +919008312904
Email: pradyut.bitmesra@gmail.com (PRADYUT)

## Abstract

According to engineers and designers, underwater construction is the most challenging type of labour. Cais- sons are sunk into water to contain water and semi-fluid material that is excavated as part of the foundations' excavation process and later forms an important component of the substructure. Scour concerns near bridges have recently gained prominence as a result of the repeated occurrence of extreme weather conditions. Thus, a bridge must be constructed with enough protective measures to avoid failure due to scourduring such intense weather occurrences.

This project is concerned with the design criteria for concrete bridges in the Brahmaputra River region, India, and its primary objective is to derive an equation that any man can use to enter the loading value and obtain the depth of the substructure directly, thereby assisting in determining the overall cost of the project, as foundations are an integral part of the bridges that stand tall.

The Pearson correlation factor is used to determine the strength of the relationship between load and depth, and the equation is derived using the idea of linear regression.

**Key words:** Underwater Construction; Scour; Concrete Bridges; Pearson Corelation Coefficient; Linear Regression

## Introduction

In the last two decades, India's population has grown expo- nentially, with an annual growth rate of 1.6 percent and a total population of 1.3 billion. This has resulted in one of the major problems of traffic congestion, which has a negative impact on travel time, air pollution, trade, and cost, and the government is doing its best to address the issue by constructing structures such as tunnels, bridges, flyovers, and subways, but it is fail- ing to meet increased demand due to high population and limited land availability, and this is where the importance comes in. The submerged designs are of enormous benefit to people and the environment. Such advancements could be used for structures, dwellings, shopping malls, exposition halls, amusement parks, cafes, inns, sports arenas, and soon.

Underwater concrete structures are a very complex mech- anism, and they are one of the most crucial components of the project's timeline. If it is not carried out appropriately, it may add to the project's costs. Cementing underwater presents unique problems for those accustomed to cementing on dry ground. Transportation, compacting, quality control, finishing, and precision all must be performed efficiently in this peculiar, and sometimes difficult, environment. There are, however, numerous fundamental points to consider, the most important of which his that while air is not required for cement to set and solidify – it does so just as well, if not better, submerged – it should be sufficiently liquid to stream into position and act naturally compacting, as ordinary vibration is impractical submerged.

Caissons and cofferdams are the methods used to construct underwater constructions. A caisson is a strong, waterproof structure that is used to support the foundations of an expanded pier, to build a solid dam, or to maintain vessels. Caissons are lowered into the earth or water during the excavation process to prevent water and semi-liquid material from entering companies, and therefore form an integral component of the foundation. A cofferdam is a fenced in area within a water environment that is meant to allow water to be displaced by air, therefore creating a dry workplace. Cofferdams are temporary steel structures that are frequently demolished once the project is complete. It is frequently employed in the creation and maintenance of oil rigs, scaffolding, and dam work. It is supported by sheet piles, ribs, and cross members.

**Scouring Around the Bridge Piers**

Analysts have conducted several trials and statisticalcal cula- tions to assess the optimum depth of scour in various soil materials. While much work has been doneto develop circumstances for predicting scour depth, experts have also worked hard to grasp scour.[12,13,15].[5,7,14,19] Bridge scour has been studied by professionals such as Raudkivi and Ettema (1983), Ahmed and Rajaratnam (1998), Chiewand Melville (1987), and Breusers et al. (1977). Shen and Schneider (1969) focused on adjacent scour along link docks, whereas Breusers et al.(1977) surveyed nearby scour around circular bridge piers. [20]Posey (1974) described how to protect erodible connect piers against under-scour by constructing an upset channel 1.5 to 2.5 dock widths away from the dock'score.

[28]Scour is defined as streambed disintegration around a block in a stream field. The total scour at a canal crossing is made up of three components. They include general, contrac- tion, and local scouring. [17],[26]

Fayun Liang, Caroline Rose Bennett, Robert L. Parsons, and Jie Han (March, 2009) conducted a survey and concluded that the behaviour of scoured pile is critical to the safety of con- structions and that an appropriate model for recreating scoured effects and a functional plan technique for assessing the secu- rity of flood-prone scaffolds should be developed [18] . To be- gin, the scouring behaviour near piles should be investigated. Second, a reliable model simulating scouring piles should be established. [18] Jean-Louis Briaud (2014) developed a method to determine the maximum depth of the scour opening around connect supports. Another approach is to anticipate the most extreme scour profundity around link supports, including piers and abutments. The method forecasts pier, contraction, and abutment scour depth. It has the advantage of incorporating a soil property: the critical velocity or shear pressure. The two essential bounds are the Froude number and the snag measurement.[25]

- The pier scour plus the contraction scour equals the overall scour depth.
- The study provided an equation for maximum pier scour depth that took several characteristics into consideration.

**Designing of Bridge**

Karthiga and co-authors (2002), examined the fundamentals of rail over connects using

IRS 25t rail route loading and street over connects using IRC class-A loading. The purpose of this study is to determine the various types of loads associated with the design and investigation of the street over scaffold and rail over connect foundations using STAAD Pro.[21]

Raheem et al (2004) performed a nonlinear static seismic assessment of a current structure. A contemporary concrete solid T-bar connection was tested using inelastic methods. The present study uses a 20-range Reinforced Concrete T Beam Bridge on SH-10 in Karnataka as a backdrop. The extension is presented in SAP 2000 programming using FEMA 356 Auto pivots and ATC40 Capacity Spectrum Method. In the dissected Bridge, Spectral Displacement Capacity exceeds Spectral Displacement Demand. So, the investigated link is secured. The variety of pivots in each of the bents were at safe execution levels. Retrofitting is no longer required.[21]

P.M. Kulkarni, Amit Katkar (2018), performed analysis in which the height of Integral Pier is maintained constant at 10M Changes in width and thickness Change the Integral Pier's breadth and thickness to see how it affects the design. The out- puts of all bridge models were segregated.[22]

M.G. Kalyanshetti and C.V. Alkunte (2012) investigated the appropriateness of IR Clive load on connected pier and viability of IR Clive load for different pier heights and extension lengths for various pier situations. Compared to square or rectangular pier, it is assumed that circular pier is more efficient, safe, and robust.[16]

**Objectives**

The following were the project's primary goals, to apply several loading situations to a bridge and compute the total depth of the foundation. To account for all key components of the loading, such as hydrological analysis, live loads, impact fac tors, dead loads, seismic and wind loads, longitudinal loads, and buoyancy/seepage while calculating depth, as specified by the codal provisions of IRC. To get a Pearson Co-relation fac- tor between foundation depth and bridge loads. Using linear regression, obtain an equation linking foundation loading and depth.

**Methodology**

The present study is carried out to study the relation between different live loading cases on bridge and the depth of foundation. To solve the stated problem, the following procedure is followed:

- Performing the designing of bridge on a case study of Dhola Sadiya Bridge(Assam).
- Performing Person Co-relation on the two sets of values – Load andDepth.
- Performing Linear Regression using MATLAB on Load vs Depth and derive an equation relating the twovalues.

The following procedures were taken to complete the design of bridges:

**Dhola Sadiya Bridge**

The 9.15-kilometre scaffold crosses the Lohit creek, a Brahmaputra tributary in between Assam and Arunachal Pradesh. The link is 540 kilometers from Dispur in Assam and 300 km from Itanagar in Arunachal Pradesh. It connects Sadia in Tinsukia, Assam, with Dhola, Assam. The bridge would re- duce travel time between Assam and Arunachal Pradesh from six hours to only one hour. Longer than Mumbai’s Bandra- Worli ocean link (3.55 km). The ocean connect is presently the country’s second longest waterway connect. The Ministry of Road Transport and Navayuga Engineering Company Ltd. began work on the Dhola-Sadiya link in 2011. The expan-sion that can resist 60 tonnes of weight, including battle tanks, cost Rs 2,056 crore. The three-path carriageway connect would also function with many hydro power projects coming up in Arunachal Pradesh, since it is the most sought-after course for diverse force project engineers. The structure will let Army es- corts get to stations near the China line. It is also expected to boost the travel sector as there is no regular civilian air terminal in Arunachal Pradesh.

When the creek is in flood, it covers a large area. The 9.15 km Length tries to conceal this but may be breached during flooding.

Positive straight relationship: In many cases, generally, the pay of an individual increments as his/her ageincrements.

Negative straight relationship: If the vehicle speeds up, the time taken to travel diminishes, and the other way around.

From the model above, it is clear that the Pearson connection coefficient, r, attempts to discover two things the strength and the bearing of the relationship from the given example sizes.

Viaducts are the design across flood plains. The Dhola side has 2600m while the Sadiya side has 2550m. The area is fraught with difficulties. One is a high level of seismicity.

$(r) =$

$\Sigma \ (x_i - x_m)\ (y_i - y_m)$

-

$\Sigma \ (x_i - x_m)^2 (y_i - y_m)^2$

(1)

The country is divided into four seismic zones based on the predicted magnitude of tremors. This region is classified as zone 5, the most powerful zone. Another hazard is strong wind speeds. Despite the fact that this is most emphatically not a beachfront zone, the breezes are strong. Wind speed in the configuration is specified as 50m/s. Together, these factors contribute to the stream’s rapid ebb and flow. The current speed of the plan is specified as 3m/s. In such circumstances, planning a building is difficult. Regardless, the dirt is composed of fine sand, which is a rather favourable situation.

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The foundation uses bored cast-in-situ piles. Due to higher forces on the stream divide, pile diameters are 1700mm across vs 1500mm in the flood plains. The number of such piles un- der a pier is also four. Heaps must counteract vertical and level loads. They transport vertical weights onto the earth by grating between soil and heap and opposing the dirt from the tip. 40m long heaps All piles (1700mm) in the stream division are 324, and in the flood, plain is 412. These piles are covered at the top. The canal divide maximum is 7.3m x 2.55m. The flood fields' cap is 6.4x6.4x2.25 meters. The heap top is kept sufficiently above low water to project the coverings. The stream division vertical load is 520 tonnes. For their presentation, heaps were loaded for 1300 tonnes. The piles were made of 40MPa con- crete. The heap's steel fortifications were 500MPa. On top of the heap cap are docks for transferring the heap from the super design.

**Pearson Co-relation Coefficient**

Pearson connection coefficient or Pearson's relationship co- efficient or Pearson's r is characterized in insights as the estimation of the strength of the connection between two factors and their relationship with one another. In straight forward words, Pearson's connection coefficient computes the impact of progress in one variable when the other variable changes.

The Pearson coefficient relationship has a high measurable importance. It takes a gander at the connection between two factors. It looks to draw a line through the information of two factors to show their relationship. The relationship of the factors is estimated with the assistance Pearson connection coefficient number cruncher. This direct relationship can be positive or negative.

For instance:

r = co-relation coefficient

$x_i$& $y_i$are values of two variables to be related $x_m$& $y_m$are mean values of variables

**Linear Regression**

Linear regression is the most fundamental and widely used form of predictive analysis. The overarching concept of regression is to look at two things: (a) Is it possible for a group of predictor factors to accurately predict an outcome (dependent) variable? (b) Which factors are significant predictors of the outcome variable, and how do they affect the outcome variable–as indicated by the size and sign of the beta estimates?

The direct condition allocates one scale factor to each information worth or section, called a coefficient and addressed by the capital Greek letter Beta (B). One extra coefficient is like- wise added, giving the line an extra level of opportunity (e.g., going here and there on a two-dimensional plot) an disregularly called the block or the inclination coefficient.

For instance, in a basic relapse issue (a solitary x and a soli- tary y), the type of the model would be:

$y = B_0 + B_1 * x$ (2)

**Components of Bridge Designed**

**Design of Segmented Box Deck Slab**

A cellular multi celled prestressed concrete box girder deck was designed. The proposed bridge deck was made up of 183 continuous spans each of 50 m. The road width was 13.2 m (10.2m carriageway and 0.9m footpath on each side). The box girder was 2m*2m with total of 15 segments. The cellular bridge deck was designed adopting M-40 Grade Concrete, Fe- 415 HYSD bars and high tensile strands of 15.2

mm diame- ter conforming to the relevant Indian Standards as Class-1 type structure conforming to the codes IRC:6-2014, IRC:112-2011, andIS:1343-2012.

The slab's live load was adjusted from 100 to 1100 kN, and the dead and live load bending moments were computed and computed the following:

Total +ve Bending Moment ($M_{up}$)=

$(1.35 * M_{d+} + 1.5 * M_{l+})$ *in kN m* (3)

Total -ve Bending Moment ($M_{un}$)

$=(1.35 * M_{d-} + 1.5 * M_{l-})$ *in kN m* (4)

Total ultimate shear force ($V_u$)=

$(1.35 * V_d + 1.5 * V_l)$ *in kN* (5)

[Table 1 about here.]

**Design of Steel Rocker Bearing**

After designing the bearing for the load from deck slabs we provided a bed plate of overall size (400*650*40) mm & top plate of overall size (400*600*40) mm with a thickness of 100 mm, and a Rocker with dimensions of, 300 mm (radius) rocker surface and 100 mm (diameter) rocker pin.

**Design of Pier**

According to the region's statistics, the High and Low Flood Levels are 106.4m and 86.80m, respectively, with an average dischargeof19200m3/sandacurrentvelocityof3m/sand silt factor of1.24.

The depth of the pier was determined to be 28 meters using these measurements, taking into account a 2-meter free board and scouring effects. Additionally, the pier was supposed to have a diameter of 1.3m. The pier cap had a dimension of (4*4*2) meters.

The pier was analyzed for stability against a variety of stresses, including those caused by dead loads and the pier's own weight, the effect of buoyancy, stress caused by braking forces, stress caused by wind forces, and hydrological forces. and Total Compressive Stress should be kept to a maximum of 2000 $kN/m^2$, due to the pier's material composition of 1:3:6 cement concrete. (Table 18.1, "Bridge Design by N. Krishna Raju"). [27]

**Design of Pile**

The piles were constructed using the following data: 1.5 m Pile Diameter, 2.5 m Safety Factor, 0.55 m Adhesion, 100 kN/m2 Cohesion, Four Piles Provided for One Pier (@1.5 m c/c). Additionally, a (4.5*4.5*2) meter pile cap wasgiven.

[Table 2 about here.]

**Design of Abutment**

Abutments were constructed using the following data: Soil Density = 18 kN/m3, Friction = 0.6, the angle of repose of the earth is 30°, and the span of the bridge is 50 meters. It was tested for failure against sliding overturning and maximum &minimum base pressures under each live load scenario. To pro- vide safety and stability, the factor of safety against overturn- ing and sliding should be more than two, and the base pressure should not exceed 2000 $kN/m^2$. [27]

**Derivation of Pearson Co - relation Coef- ficient**

Pearson Co-relation factor ($r$) =

$\sqrt{\sum}(x_i - x_m)(y_i - y_m)$ $\frac{2 \quad 2}{(x)(y-y)_m}$

Where,

$x_i$= Total Load transferred from Deck Slab + Self weight of piers in (kN)

$x_i$' = Live Loading on bridge in (kN) $y_i$= Depth of Piles in (m)

$y_i$' = Total Depth of Substructure – Pier + Piles in (m)

[Table 3 about here.]

Where,

Pearson Co-relation factor for Live Loading vs Total Depth of Substructure r1 =0.979

Pearson Co-relation factor for Live Loading vs Depth of Piles r2 =0.979

Pearson Co-relation factor for Total Loading vs Total Depth of Substructure r3 = 0.985

Pearson Co-relation factor for Total Loading vs Depth of Piles r4 = 0.985

**Results**

- Equation relating Live Loading vs Total Depth of Sub structure:

$y = 0.051929x + 48.005718$ (6)

- Equation relating Live Loading vs Depth ofPile:

$y = 0.051929x + 20.005718$ (7)

- Equation relating Total Loading vs Total Depth of Sub struc ture:

$y = 0.010614x + 22.142912$ (8)

- Equation relating Total Loading vs Depth ofPile:

$y = 0.010614x - 5.857088$ (9)

**Conclusion**

The main aim of the project was to derive a general relation- ship between two arbitrary variables – load and depth required for the designing of bridges. In a country such as India it is still a big task to initiate the construction of the bridges and one of the most important aspect of the bridge design is to determine the depth of substructure required.

This project had helped to create a general relationship for a limited region as a case study where any common man with the help of the equation derived can come up with the required depth of substructures for different loading cases in the Brahmaputra River region for an overall assumed and obtained soil conditions and river regime conditions.

The Pearson Co-relation Factor derived signifies that loading and depth are very closely related to each other as the value lies nearer to 1.0. Also, it was observed that the coefficient is not much affected by the dead weight of the structures but by the live loading being applied on the deck slab and it is one of the important factors relating to the design of the bridges and in the cost of the structures. The substructure is a very essential part of the bridges and under water resistance and construction is directly related to the depth and hence is a critical component of the design of the structures.

The equation derived using linear regression concept with the help of MATLAB for the four different cases where Y axis shows Depth and X axis shows Loading. The overall least square error varies between 0.4 % to 0.8% among the four cases.

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**Author biography**

**PRADYUT ANAND** Pradyut Anand is a doctoral candidate at the Birla Institute of TechnologyinMesraRanchi,India.Hedid his Master of Technology in Structural En- gineering from the Birla Institute of Tech- nology Mesra in Ranchi, India and Bach- elor of Technology from ManipalInstitute of Technology India.

**List of Tables**

| Live Loading(kN) | Q (kN) | $M_{l-}$(kN m) | $M_{l+}$(kN m) | $V_l$(kN) | $M_{up}$(kN m) | $M_{un}$(kN m) | $V_u$(kN) | Effective Depth (mm) | Total Load transferred from Deck Slab (TL) (kN) |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 20 | 8.4 | 7.24 | 12 | 13.31 | 16 | 37.116 | 55 | 1008 |
| 200 | 35 | 14.7 | 12.67 | 21 | 21.45 | 25.45 | 50.62 | 68 | 1233 |
| 332 | 54.6 | 25.2 | 21.72 | 36 | 35 | 41.21 | 73.116 | 86.41 | 1608 |
| 400 | 70 | 29.4 | 25.34 | 42 | 40.46 | 47.41 | 82.116 | 92.773 | 1758 |
| 554 | 95 | 39.9 | 34.4 | 57 | 54 | 63 | 104.6 | 107.05 | 2133 |
| 700 | 120 | 50.4 | 43.44 | 72 | 67.61 | 79 | 127.116 | 120 | 2508 |
| 800 | 132 | 55.44 | 47.784 | 79.2 | 74.13 | 86.7 | 138 | 126 | 2688 |
| 900 | 150 | 63 | 54.3 | 90 | 83.9 | 97.91 | 154.12 | 134 | 2958 |
| 1000 | 166 | 70 | 61 | 100 | 92.6 | 108 | 168.5 | 140 | 3198 |
| 1100 | 185 | 77.7 | 67 | 111 | 103 | 120 | 185 | 150 | 3483 |

**Table 1:**LiveLoadingonDeckSlabwithEffectiveDepthandUltimateShearForce[5,13,15]

| Live Loading (kN) | Total from (kN) | Load Deck | transferred Slab (TL) | Factored Total Load (kN) | Length of Pile (m) | Safe Load on Pile Group (kN) |
|---|---|---|---|---|---|---|
| 100 | 2912 | | | 3203.2 | 24.78 | 20443 |
| 200 | 3362 | | | 3698.2 | 29.55 | 22443 |
| 332 | 4112 | | | 4523.2 | 37.52 | 25423 |
| 400 | 4410 | | | 4851 | 40.68 | 27034 |
| 554 | 5192 | | | 5710.66 | 48.98 | 30473 |
| 700 | 5912 | | | 6502.66 | 56.62 | 33641 |
| 800 | 6272 | | | 6900 | 60.45 | 35227 |
| 900 | 6 | | | 7500 | 66.18 | 37603 |

| | | | | |
|---|---|---|---|---|
| | 8 | | | |
| | 1 | | | |
| | 2 | | | |
| 1000 | 7 | 8030 | 71.36 | 39750 |
| | 3 | | | |
| | 0 | | | |
| | 0 | | | |
| 1100 | 7 | 8650 | 77.3 | 42214 |
| | 8 | | | |
| | 6 | | | |
| | 0 | | | |

**Table 2:** Pile Length and Safe Load for different Loading cases [13, 25, 28]

| $x_i$ | $x_i$’ | $y_i$ | $y_i$’ | $(x_i-x_m)$ | $(y_i-y_m)$ | $(x_i-x_m)$’ | $(y_i-y_m)$’ | $(x_i-x_m)*(y_i-y_m)$ | (xi-xm)’*(yi-ym)’ |
|---|---|---|---|---|---|---|---|---|---|
| 2912 | 100 | 25 | 53 | -2502.4 | -26.61 | -508.6 | -26.61 | 66588.864 | 13533.846 |
| 3362 | 200 | 30 | 58 | -2052.4 | -21.61 | -408.6 | -21.61 | 44352.364 | 8829.846 |
| 4112 | 332 | 37.6 | 65.6 | -1302.4 | -14.01 | -276.6 | -14.01 | 18246.624 | 3875.166 |
| 4410 | 400 | 41 | 69 | -1004.4 | -10.61 | -208.6 | -10.61 | 10656.684 | 2213.246 |
| 5192 | 554 | 49 | 77 | -222.4 | -2.61 | -54.6 | -2.61 | 580.464 | 142.506 |
| 5912 | 700 | 57 | 85 | 497.6 | 5.39 | 91.4 | 5.39 | 2682.064 | 492.646 |
| 6272 | 800 | 61 | 89 | 857.6 | 9.39 | 191.4 | 9.39 | 8052.864 | 1797.246 |
| 6812 | 900 | 66.5 | 94.5 | 1397.6 | 14.89 | 291.4 | 14.89 | 20810.264 | 4338.946 |
| 7300 | 1000 | 71.5 | 99.5 | 1885.6 | 19.89 | 391.4 | 19.89 | 37504.584 | 7784.946 |
| 7860 | 1100 | 77.5 | 105.5 | 2445.6 | 25.89 | 491.4 | 25.89 | 63316.584 | 12722.346 |
| **xm = 5414.4** | **xm’= 608.6** | **ym = 51.61** | **ym’ = 79.61** | | | | | **Σ 272791.36** | **Σ 55730.74** |

**Table 3:** Computation for Pearson Co-relation Coefficient [4, 13]