Inexpensive Design & Cost Optimization of Spill through Abutment with Pre-Stressed Superstructure

Sudip Kumar Swain[1] Ankit Sethi[2]
[1]M.Tech. Student [2]Assistant Professor and Head
[1,2]Department of Civil Engineering
[1,2]WCTM, Farukhnagar, Haryana, India

Abstract — This thesis presents the executional viability and cost benefits of spill through type abutment with higher embankment height and long spans. The detailed structural design of open footing, substructure and superstructure shall be submitted in this technical paper in order to better understand the structural analysis and behaviour. The Spill-through abutments primarily consists on rectangular or circular type columns placed at intervals to let the soil spill between them. While they do not include wing walls or return walls to retain the soil embankment, the deck is placed/casted on girders rested on bearings. Streams or roadways are to pass between the abutment locations. The width of the abutment cap is based on the accommodation of bearing location and seismic stoppers. When the embankment height is high enough and the existing stream or waterway is undisturbed then spill through abutment is considered more inexpensive and cost optimum than wall type abutment. The open footings are constructed by initially excavating soil upto the bottom of footing. During the initial stages of site execution, the complete open footing is visible and thus is referred to as open foundation. Each footing is intended to carry the load from the individual columns and distribute the same over a larger area, so that the safe bearing capacity of the soil is not exceeded. Pre-stressing or specifically post-tensioning is the application of axial force to increase the moment carrying capacity of concrete or other materials using high strength steel strands or bars, denoted as tendons. Post-tensioning is applicable is a variety of construction sectors including buildings, parking areas, bridges, stadiums, soil anchors, water-tanks, etc to name a few. Although, post-tensioning systems require expertise for fabrication, assembly and installation, the basic application is easily explainable. In many cases, posttensioning allows construction that would otherwise be impossible due to either execution constraints or architectural requirements. A post-tensioning system shows application of tendons which are stretched by hydraulic jacks so that system has no tensile stresses developing at any section and is held in place by anchoring devices.

Keywords: Design & Cost Optimization, Spill, Abutment, Pre-Stressed Superstructure

I. INTRODUCTION

A spill-through abutment refers to a type of bridge end support that permits the flow of earth through gaps along the length of the abutment. This design involves positioning columns beneath the deck beam, allowing space between them for the earth to freely spill through. Substructures and foundations are substantial elements of bridges, frequently accounting for more than half of the total bridge cost. Consequently, the methods employed for their analysis, design, and detailing are of paramount importance as they can significantly impact both the structural performance and the overall project budget.

The existing vast reservoir of knowledge extensively records the collaborative endeavours aimed at advancing both the theory and practice of bridge engineering. This progress is evident in the development of piers, abutments, walls, and foundations, as well as in our current comprehension of soil-structure interaction. Notable improvements are reflected in the use of materials with better physical and structural characteristics, and in the rational and more explicit analysis of structural behaviour.

In the present synthesis of the new and old concepts, traditional approaches have been integrated with recently evolved design philosophies, producing design options that enhance the field of structural analysis. Thus, the deterministic methodology rep resented in the past by the allowable stress design can now be supplemented or completely replaced by load factor design, a statistically-based probabilistic approach. Although some engineers believe that certain discernible gaps and inconsistencies may persist for some time in this integration, the general consensus is that the field of bridge design now offers more viable alternatives that can be effectively applied to the entire structure and its foundation. The adoption of load factor design has become a crucial aspect of structural analysis across various areas of structural engineering worldwide. This approach incorporates insights from completed research and informed judgment while introducing novel provisions and significant changes. It deals with load and force models, load factors, nominal resistance and resistance factors, limit states, and the soil-structure system on a global scale. An inherent continuation involves contemplating the variability in the properties of structural elements, which is treated as the variability in the loads.

In this thesis the detail design parameters will be discussed. There are several load factors which will leads to ultimate design of foundation substructure and superstructure.

The open type foundation is generally used where raft foundation can be provided and SBC requirement is less compared to pile and well.

Abutments are the end supports of a bridge, where it connects with the approach roadway. Their function is twofold: to transmit the reactions from the superstructure to the foundation, and to retain the earth embankment of the approach roadway. Thus, the main loads on the abutment come from the superstructure or are induced as earth pressures.

Continuous bridges with several spans usually are designed with expansion ends, and therefore abutments are not required to resist longitudinal forces. Sometimes, the friction or shear force produced at expansion bearings on abutment seats may be considerable, and its inclusion in the

analysis can thus have an additive effect on earth pressures and surcharge loads. Alternatively, for continuous bridges, the longitudinal forces can be transmitted at one location only provided that expansion and contraction are not restricted. In many instances the most suitable point of longitudinal restraint is at one abutment. Where abutments are massive and rigid, they are considered a suitable location to balance longitudinal forces from the superstructure. By the same rational approach, some engineers choose to resist lateral forces also at the abutments, and provide slender piers to carry vertical loads only.

The spill through abutment is generally used where span is large and linear waterway is not disturbing the abutment location.

The spill-through abutment reduces the earth pressure, resulting in lower forces during seismic design and, consequently, optimizing costs compared to other sub-structure types. This type of abutment allows soil to spill through gaps along its length, effectively reducing the earth pressure.

Pre-stressing is the process of applying compressive force to concrete to counteract tensile stresses generated by applied loads. In other words, it involves placing an initial load on a structure to enable it to withstand tensile stresses arising from subsequent loads during its service life. This practice dates back to ancient times and can be observed in various examples, such as the behavior of bicycle spokes under loading. Pre-stressed concrete, on the other hand, is a specific type of concrete where internal stresses of a controlled magnitude are induced to effectively counterbalance the stresses caused by external loads to the desired extent. The minimum grade of concrete in pre-stressing technique is M40 for pre-tensioning and M35 for post tensioning. The tensile strength of concrete is only 8-14% of its compressive strength of concrete.

The spill-through abutment is prone to experiencing scouring issues. As evident from the photos below, each abutment comes in contact with the soil strata, which contributes to the scouring phenomenon.

II. Advantage with Spill Through Abutment

1) The spill-through abutment comprises a beam that supports the bridge seats and two or more columns that support the beam, resulting in a reduced dead load on the substructure and requiring less seismic force on the foundation.
2) The spill-through abutment can be employed in cases where an additional span might be added to the bridge at a later time.
3) Spill-through abutments are the most cost-effective type of abutment and are generally the easiest to construct.
4) Spill-through abutments eliminate the challenges of achieving sufficient compaction near the relatively tall walls of closed abutments.

The structure design will be done as portal frame. The IRC codes that are considered during design and analysis are IRC:6-2017, IRC:112-2020, IRC:78-2014, IRC: SP 13-2004 and literature books.

We will also see how the term economic and viable are justified through the detail design and execution point of view. The basic design parameters like seismic zone, exposure condition, creep factor, cover all will be considered while detail design and we will go step by step from force analysis (DL + SIDL + LL + EP + Seismic etc.) to reinforcement detailing. For further reference image is attached in order to more understand the drawing.

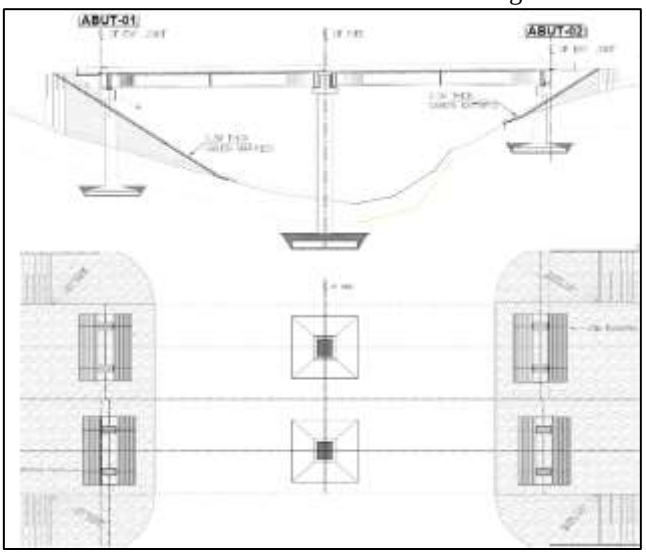

Fig. 1: Elevation and plan of a typical bridge with spill-through abutment and pre-stressed superstructure

III. Methodology for Spill Through Type Abutment Design

In the study, following spill through abutment with post tension super structure there will be separate analysis for foundation + substructure and super structure.

In order to design foundation and substructure following steps will be considered.

- Static Load Calculations
- Seismic & Wind Force Calculations
- Basic Design Data for Abutment
- Design of Abutment Shaft (ULS & SLS Checks)
- Check for Foundation Base Pressure
- Design of Foundation (ULS & SLS Checks)
- Design of Abutment Cap (ULS, SLS & Corbel Checks)
- Design of Seismic Arrestors (ULS & SLS Checks)

In order to design post tension superstructure following steps will be considered.

- Basic Design Inputs for PSC Girder
- Sectional Properties
- Load Calculations
- Prestress Cable Details

There are many softwares available in the industry for the design of bridge but particularly user friendly software is Midas-Civil we will be using for the design purpose and for the dimension detailing and general arrangement of drawing AutoCAD software will be used. After extracting the summary of forces for foundation, substructure and superstructure, checking of moments, shear forces and stress limit will be done on excel. The prestressing and reinforcement detailing for the design check will be put on excel in order to checking of strength, capacity and stress limit.

IV. CONCLUSIONS

- Opting for rectangular columns proves more cost-effective than wall-type abutments due to reduced concrete volume.
- Soil spillage can be efficiently managed and protected using pitching techniques, minimizing scouring risks and reducing earth pressure.
- Pre-stressed superstructures require less thickness compared to RCC girders, resulting in economic benefits.
- Spill-through abutments are advantageous for larger spans where linear waterway obstruction is absent at the abutment location, contributing to cost savings.
- Load bearing diaphragm is more convenient because bearing is placed above column a compression forces mainly comes into picture so cap thickness can be reduced by providing designed reinforcement in column.
- Post-tensioning tendons are considered "active" reinforcement, providing effectiveness even without concrete cracks
- Post-tensioned structures can be designed to exhibit minimal deflection and cracking, even under full load.
- Semi-integral abutments, isolated from bridge thermal movements, are ideal for connecting to adjacent retaining walls.
- Short semi-integral abutments can be constructed behind Mechanically Stabilized Earth (MSE) wall systems, significantly reducing height and wingwall length, thereby saving on concrete and piles.
- Post tension girder is designed considering 19nos. of strand with Dead Load, Superimposed Dead Load, Live loads (IRC Class A & IRC 70R Wheeled loading) and their combinations as per IRC-6-2014 have been considered in the analysis. Based on the analytical study of three bridge models, following conclusions have been drawn.
- Spill-through or open abutments are often used for potential future span additions or unique construction challenges, situated on columns that extend from the natural ground
- Compaction challenges arise when placing embankment materials around columns and under the abutment cap. Early settlement and erosion are common issues with such abutments.
- If the abutment is to be used as a future pier, it is important that the wings and backwall be designed and detailed for easy removal. Construction joints should be separated by felt or other acceptable material. Reinforcing steel should not extend through the joints. Bolts with threaded inserts should be used to carry tension stresses across joints.
- The absence of waterproof expansion joints reduces future maintenance requirements.
- Taller abutments are feasible, making them suitable for urban locations requiring aesthetic treatments or reduced span lengths.

REFERENCES

[1] BACHUS, R. C., and BARKSDALE, R. D. (1989). "Design Methodology for Foundations on Ston Columns," Proceedings, Foundation Engineering: Current Principles and Practices American Society of Civil Engineers, Vol. 1, pp. 244–257.
[2] BARRON, R. A. (1948). "Consolidation of Fine-Grained Soils by Drain Wells," Transactions, American Society of Civil Engineers, Vol. 113, pp. 718–754.
[3] BASORE, C. E., and BOITANO, J. D. (1969). "Sand Densification by Piles and Vibroflotation," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol. 95, No. SM6, pp. 1303–1323.
[4] BROWN, R. E. (1977). "Vibroflotation Compaction of Cohesionless Soils," Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol. 103, No. GT12, pp. 1437–1451.
[5] BURKE, G. K. (2004). "Jet Grouting Systems: Advantages and Disadvantages," Proceedings, GeoSupport 2004: Drilled Shafts, Micropiling, Deep Mixing, Remedial Methods, and Special Foundation Systems, American Society of Civil Engineers, pp. 875–886.
[6] CHRISTOULAS, S., BOUCKOVALAS, G., and GIANNAROS, C. (2000). "An Experimental Study on Model Stone Columns," Soils and Foundations, Vol. 40, No. 6, pp. 11–22.
[7] D'APPOLONIA, D. J., WHITMAN, R. V., and D'APPOLONIA, E. (1969). "Sand Compaction with Vibratory Rollers," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol. 95, No. SM1, pp. 263–284.
[8] HUGHES, J. M. O., and WITHERS, N. J. (1974). "Reinforcing of Soft Cohesive Soil with Stone Columns," Ground Engineering, Vol. 7, pp. 42–49.
[9] HUGHES, J. M. O., WITHERS, N. J., and GREENWOOD, D. A. (1975). "A Field Trial of Reinforcing Effects of Stone Columns in Soil," Geotechnique, Vol. 25, No. 1, pp. 31–34.
[10] ICHIMOTO, A. (1981). "Construction and Design of Sand Compaction Piles," Soil Improvement, General Civil Engineering Laboratory (in Japanese), Vol. 5. pp. 37–45.
[11] JOHNSON, S. J. (1970a). "Precompression for Improving Foundation Soils," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers. Vol. 96, No. SM1, pp. 114–144.
[12] JOHNSON, S. J. (1970b). "Foundation Precompression with Vertical Sand Drains," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers. Vol. 96, No. SM1, pp. 145–175.
[13] Clark, L.A. (1982) Concrete Bridge Design to BS5400, Cement and Concrete Association, London.
[14] Green, J.K. (1973) Detailing for Standard Prestressed Concrete Bridge Beams, Cement and Concrete Association, London.
[15] Hambly, E.C. (1991) Bridge Deck Behaviour (2nd edn.), E&FN Spon, London.

[16] Liebenberg, A.C. (1992) Concrete Bridges: Design and Construction, Longman Scientific and Technical, Harlow.
[17] Mathivot, J. (1983) The Cantilever Construction of Prestressed Concrete Bridges, Cement and Concrete Association, London.
[18] Pennells, E. (1978) Concrete Bridge Designer's Manual, Cement and Concrete Association, London.
[19] Podolny, W. (1982) Construction and Design of Prestressed Concrete Segmental Bridges, Wiley, New York.
[20] Strasky, J. (1995) Pedestrian Bridge at Lake Vranov, Czech Republic, Proceedings of the Institution of Civil Engineers, 108, August 1995.
[21] Woolley, M.V. and Clark, G.M. (1993) Post-Tensioned Concrete Bridges, The Structural Engineer, 71 Nos 23 and 24.
[22] Kumar Ch. Phani, Babu S.V.V.K, Sai Ram D Aditya, Analysis and Design of Prestressed Box-girder Bridge by IRC: 112-2011, International Journal of Constructive Research in Civil Engineering (IJCRCE), Volume 2, Issue 2, 2015.
[23] ABOSHI, H., ICHIMOTO, E., and HARADA, K. (1979). "The Compozer—a Method to Improve Characteristics of Soft Clay by Inclusion of Large Diameter Sand Column," Proceedings, International
[24] ABOSHI, H., ICHIMOTO, E., and HARADA, K. (1979). "The Compozer—a Method to Improve Characteristics of Soft Clay by Inclusion of Large Diameter Sand Column," Proceedings, International
[25] Conference on Soil Reinforcement, Reinforced Earth and Other Techniques, Vol. 1, Paris, pp. 211–216.
[26] AMERICAN SOCIETY FOR TESTING and MATERIALS (2007). Annual Book of Standards, Vol. 04.08, West Conshohocken, PA.
[27] LEONARDS, G. A., CUTTER, W. A., and HOLTZ, R. D. (1980). "Dynamic Compaction of Granular Soils," Journal of Geotechnical Engineering Division, ASCE, Vol. 96, No. GT1, pp. 73–110.
[28] MATTES, N. S., and POULOS, H. G. (1969). "Settlement of Single Compressible Pile," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 95, No. SM1, pp. 189–208.
[29] MITCHELL, J. K. (1970). "In-Place Treatment of Foundation Soils," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol. 96, No. SM1, pp. 73–110.
[30] MITCHELL, J. K., and FREITAG, D. R. (1959). "A Review and Evaluation of Soil–Cement Pavements," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol. 85, No. SM6, pp. 49–73.
[31] MITCHELL, J. K., and HUBER, T. R. (1985). "Performance of a Stone Column Foundation," Journal of Geotechnical Engineering, American Society of Civil Engineers, Vol. 111, No. GT2, pp. 205–223.

