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"Influence of Artesian Groundwater Pressure on Foundation Stability and Design"

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ABSTRACT: India's rapidly expanding economy has led to extensive infrastructure development, making it essential to adopt cost-effective and efficient construction methods. Modern transportation bridges are commonly supported by pile foundations, which transfer structural loads to deeper, stronger soil layers beneath weak surface soils. Shallow foundations are generally unsuitable for such conditions. Piles are characterized by their considerable length and relatively small cross-sectional area.

One of the major geotechnical challenges encountered in bridge construction worldwide is the presence of artesian groundwater conditions at foundation levels. Even low artesian pressures can destabilize foundations and threaten bridge safety. Therefore, monitoring artesian pressure and implementing measures to enhance foundation stability are of critical importance.

Compared to pile foundations, well foundations are significantly more economical, with construction costs approximately one-third lower. However, inadequate soil investigations and a shortage of skilled technical personnel often increase the risk of foundation-related failures. This study presents a unique investigation into cases of bottom plug failure in well foundations and proposes a safe and effective construction methodology for bridge foundations under artesian conditions.

The research focuses on the bridge constructed across the Chambal River on the Ater–Jaipur Highway. The site is characterized by soil strata containing artesian groundwater at varying depths. The foundation design is based on two key considerations: first, preventing bed boiling (quick condition) even under maximum scour conditions; and second, ensuring the availability of a minimum thickness of soil cushion between the foundation level and the artesian-bearing stratum during construction.

In situations involving low artesian pressure, the construction of false steining is essential to counteract the effects of upward water pressure. Deep foundations penetrating artesian aquifers are particularly vulnerable to soil washout during and after construction. In well foundations, failures of the bottom plug, errors during sinking operations, or defects in false steining can lead to post-construction settlement or sinking of the foundation. These failures occur due to the upward movement and erosion of soil particles caused by artesian pressure.

Artesian pressure develops when groundwater is confined between impermeable soil or rock layers, creating pressure within the aquifer. Understanding these conditions presents a significant challenge for civil and geotechnical engineers responsible for foundation design and construction. This dissertation provides a detailed examination of artesian groundwater conditions and their influence on foundation design.
The well foundation construction method described in this study offers a safe and practical solution for deep foundations that must penetrate the confining layer of an artesian aquifer. The artesian aquifer at the study site exhibits a hydraulic head approximately 4 meters above ground level. The research also examines the reasons for the widespread adoption of well foundations in India and highlights how improved soil investigation practices and the involvement of experienced technical experts can significantly reduce construction failures.
The study concludes that bottom plug failures can be effectively mitigated through the provision of intermediate plugs and relief wells. These measures improve foundation stability and reduce the risks associated with artesian groundwater conditions.
Keywords: Artesian Conditions, Low Artesian Pressure, High Artesian Pressure, False Steining, Bed Boiling, Soil Cushion, Deep Foundation, Well Foundation, Bottom Plug Failure, Relief Wells.

INTODUCTION: The water embedded in the underground gravel, sand and rock. The water has the pressure and it flows. This layer of the soil is called as aquifer. The positive pressure in water is responsible for the filling of water inside a well excavated for the foundation and this becomes constant when the hydrostatic balance is obtained. In case of intrusion of the aquifer open to atmospheric pressure like well, shaft or borehole initiates the up thrust and it leads to soil erosion finally instability in the civil structures. The deep foundation like well foundation having the artesian layers can result into the failure of the foundation after the construction. The soil erosion is triggered by sudden artesian pressure and the movement is naturally upwards. The global practice has been the use of water circulation drilling or polymer bentonite slurry to flush the well. The platforms above the ground level are constructed in the soil having embedded artesian layers. This method has been popular over several decades. But, this method is not foolproof and the evidence is the failure of few deep foundations like one discussed in this paper. Deep foundations under the artesian conditions can create hazards and lead to big problems during, and post installation. This is due to the high risk of soil erosion resulting from the foundation elements sometimes work like pathways or pits responsible for the upward movement of soil particles carried by groundwater following the newly introduced pressure relief openings to surface. This has been the most popular because it can manage the risks associated with breaching of the confining layer of an artesian aquifer.

Fig 1:- Artesian Water Pressure

OBJECTIVES OF THE STUDY:

1. To study the causes of the failure of the well foundations in artesian conditions.
2. To find out more economical method design and construction of the deep foundation
3. To compare the existing method and suggest economical and safe method of deep foundation design in artesian conditions

LITERATURE REVIEW:

OnurKacar, Andrew Cushing, and Michael R. Lewis.et.al.(2019) This research paper describes the application of high capacity micropile and its testing close to the bridge piers. The cofferdam is constructed to keep away water. The micropileis put into service using case drilling and air flushing. This new method saves time and cheaper equipment as water flushing requires costlier machinery. The authors have conducted the load tests to check the validity of axial loads. The results are enough to prove the strength of the micropile foundation.

Mohan Vasant Jatkar and ShirishWasudeo Deshpande et.al. (2018) The research scholars in this paper have described the technical difficulties encountered by geotechnical experts and bridge construction engineers. It is observed fact that the cost of such bridges goes high because of the unpredictable nature of the soil. The common problem is the heavy cost of testing, design, and implementation. The sudden failure due to artesian pressure is beyond the human prediction. The solution to failures in such a situation is not well developed. The paper briefly describes the important bridges constructed throughout the country over Indian rivers. The case studies have also been discussed in short.

NareshGurpersaud, Zhong Han, Mark Montgomery &Hiu Lee et.al.(2018) The authors have described a case of bridge construction in Canada. The work is based on the use of micropiles which are successfully used with more steel. The artesian water was found in this site and the artesian layers were penetrated using small-sized piles with micro diameter. The micropilesare drilled across the layers of the earth across the earth layers with artesian flow. The fourteen piles were designed for required axial loading of the order 1000kN. The paper describes grout-flush pile. This is most elegant design for such conditions.

Anthony Wade Fisher et.al. (2017) This study is based on the three hundred fifty wells which are made to work in the basin. It has been found that eighty wells with the artesian flow occurring at about five meters but this effect is more at three-meter level.

Hossam Elbadry Ashraf Eid el.al.(2016) In this work the author has contemplated on the issues which the foundation technocrats face while constructing the deep foundations in soft soil having artesian pressure embedded at depth. The foundation design and construction in such conditions is cost-effective and requires highly qualified and skilled work force. The study reveals the limitations of modern design methods and it calls upon finding a better and cheaper technical solution.

HossamElbadryet.al.(2016)have discussed factual and hazardous problems of the very deep deposits of very soft clay soils for structural foundations. It is a hypothesis to consider the technical methods applied in the soft soil by geologists and engineers of this field are based on the economic benefits of the past projects. The economics of the projects is driving force which controls the selection of the methods and tools in the design of the foundations in soil with the artesian flows and their required cost and their construction problems which need the highest level of accuracy. The modern prevalent methods are not safe.

M.Heidarzadehet.al.(2015)have presented the case study of a dam, where relief wells have been constructed in the close vicinity Karkheh Dam in Iran. The chai of the relief wells were constructed to neutralize the artesian pressure. The safety of the toe of the dam was ensured by providing sufficient number of the relief wells. The preexisting wells were improved to reduce the uplift pressure.

Dan Brown et.al.(2015) The author has investigated the use of a different type of pile foundation which can be used as a safe and economical solution to the deep foundation issues. The small diameter piles also called as micro piles can be used. The micropiles can be installed using the small machine and installation envelope is quite small in size as compared with the normal piles. Post-installation testing and monitoring are very easy. The compact equipment and lower cost of the transportation of the material and machine is the most attractive feature. In the American continent, the drilled pile foundation is becoming the first choice. The micropile design has become the standard and has been incorporated in the IBC and AASHTO code. The technological advancement in the drilling machinery has also made the pile foundation economical and safer.

Donald E. Splitstone et.al.(2010) The paper is based on the detailed analysis of the foundation design based on the Micropiles and comparison is made with the already existing structure. The weaker foundation has been replaced with the safer micropiles.

Jim Bruce et.al. (2009) has described a case study, detailing a recent application of this appropriate approach at an urban transportation infrastructure construction project requiring deep foundations in Canada. The micropile based deep foundations are constructed which cut across the barrier imposed by the aquifer layers existing in the layers of the soil. The authors have observed the head of two meters. The strong soil-bonded miropilesare used to provide the strong foundation to support the transportation bridge.

Anil Mishra et.al.(2009) The paper describes the use of micropiles in the rehabilitation projects. The existing structures are further strengthened to support the new incremented or modified structures. The micropilescan be pulled and the installation machinery is compact and can reach the congested sites. The existing structures are intact during the renovation of the existing structure. The restoration of the historic buildings becomes easy and economic. This does not require the demolition of the structure.

THE PROJECT DESCRIPTION The Chambal river is the perennial river of North Madhya Pradesh, India. It has great geological significance. This river is betweenVindhyanchal and Aravali Chain of mountains.The Chambal flows through Kota in Rajasthan ,Bharatpur, Morena in Madhya Pradesh and joins Yamuna in Uttar pradesh. It flows through mountains and plain

The Chambal joins Yamuna and further flows into Ganga, the Great Historic Holy River of the country. The three states of India are traversed by the river. Rajasthan, Madhya Pradesh and Uttar Pradesh enjoy the benefits of the Chambal. Shipra, Kali Sindh and Parvati join Chambal in M.P. It acts like a boundary between Madhya Pradesh and Uttar pradesh. The underground water flow is the result of water gradient. This leads to the artesian conditions in the region where the Chambal flows in the plains.

Cross sectional profiles at the bridge location showing the distribution of the strata along the bridge alignment is presented on the water column above the ground level at the borehole location at the time of the investigation. The artesian water overflowing from the casing during geotechnical investigation. It may be stated that three confined strata with artesian pressure is encountered as listed below

Table : River Chambal Artesian Head & Description of Strata

Bore hole No	**Depth of Strata With artesian pressure. (M)**	**Measured Artesian Head above GL(M)**	**Description of Strata**
P-1	6.8-7.55	2	Fine Sand
P-2	13-21.76	3	Coarse Sand with Boulder
P-3	11.65-32.55	1	Blackish soil with clay patch fine gravels
P-4	25.77-42.14	2.5	Yellow soil with clay patch fine gravels
P-5	27.62-42.52	4	Yellows oil with clay patch fine gravels

THE PROPOSED FOUNDATION DESIGN The seventeen span bridge has two abutments. The total length of bridge 1000 m and the spans are 50.000 m long. The Low Water Level (LWL) 80.00 m and the Normal Scour depth 24.07 m. The downward load at pier top is estimated to be about 550 Ton. For such bridge with high load and substantial, scour (12 m at pier location). it is normal practice to provide well foundation. For this bridge

1. High Artesian Pressure

FOUNDATION DEPTH Because of multiple artesian layers, the depth of foundation will depend upon the depth of each layer. In case the first artesian layer is deep, shallow well foundation with well tip in clayey strata, which is sufficiently above the strata with artesian pressure, is a suitable foundation scheme.

In case of artesian layer being at shallow depth, the well foundation may be required to go deeper, crossing one or two artesian layers. The well tip may be founded below the artesian layer, preferably in clay layer, which is sufficiently above the underlying artesian layer.

A deep well with well tip in sand layer may be required at some cases depending upon the stratigraphy. Construction / sinking of the well should be done during the fair weather season during which the artesian pressures are relatively small. In this case, adequate precautions should be taken to ensure that the bridge remains stable even during the worst situation.

DESIGN CRITERIA

In addition to the usual checks for bearing capacity safety factor and settlement of the well foundation under the anticipated load, foundation design in strata with artesian flow is governed by the following technical considerations:

The stability of riverbed is to be ensured against boiling due to artesian pressures (quick condition) from various layers if scouring up to maximum scour level takes place.

It should be ensured that sufficient soil cushion is available between foundation tip level and the artesian level, so that the artesian pressure does not puncture through soils below founding level during construction period. If it is not possible to provide sufficient thickness of the soil cushion, necessary precaution should be taken during the construction stage by providing positive head of water by providing false steining to counter-balance the artesian pressure.

STABILITY OF RIVER BED (BED BOILING) The stability of bed against quick condition under maximum scour condition is to be checked for the foundation system. In case, due to artesian conditions, bed boiling (quick condition) is likely to take place, necessary bed protection will be required to minimize scouring and to avoid instability due to boiling of bed. If effective overburden pressure at artesian level during the time the maximum scour has occurred becomes negative (less than 0), "bed boiling" (quick condition will occur. The artesian will puncture through the overburden resulting in instability of the riverbed. Effective overburden pressure at artesian Level

$= q' = \Upsilon t\, a - u$,where

Υt = bulk density of soil

a = thickness of soil strata between max. scour level and artesian level

= RL of scour level − RL of artesian level

u = Pore water pressure

= Maximum expected artesian pressure in artesian layer.

$= \Upsilon w$ [(RL of GL − RL of strata with artesian head) + p]

Υw = unit weight of water

p = artesian head above ground level

SOIL CUSHION THICKNESS At the well tip level, it is essential that the soil cushion between the well tip and the artesian (sand) layer is sufficient to resist the uplift pressure due to the artesian condition. This condition is most critical during the construction period. While the well is being sunk, the water level inside the well should be maintained above ground level or water level in the river, whichever is higher. If boiling is observed while sinking, water level inside the well should be increased to create a positive head to counter balance the artesian head by provision of false steining

LOW ARTESIAN PRESSURE Establishment of artesian at foundation of bridge has been a common geotechnical difficulty observed in many bridge projects throughout the world. As such artesian may result in destabilized foundation, consequently endanger the bridge safety monitoring of artesian at bridge foundation, and strengthen the stability of bridge against it is of critical importance. The most effective engineering solution to improve bridge safety against artesian is:

CONSTRUCTION OF FALSE STEINING

The deep foundations where low water pressure exists, the false steiningis constructed to counteract the artesian pressure. This is the solution which protects the bridge structures over entire service period. The local artesian head is relieved by the construction of false steining and this requires expert technical workforce. The wooden piles are provided below at 300 mm/cc spacing. This results into water tight surroundings and thus responsible for the stability of the soil. . The platform is constructed with double the diameter of the well and piles are driven along the boundary and sand bags are placed between the piles. This behaves like a coffer dam.

Fig. Construction of false Steining with cofferdam

Bottom Plug:-The well is provided at founding level. At the founding level the bottom plug is constructed. The soundness test is conducted to test the bottom plug. The water must flow at rate of 10 cm/hour as per the MORTH specifications**.** But, when there is Artesian Pressure present below at Founding Level it's impossible to plug well as a result cement will be washed out in plugging and there will be segregation of aggregate so the plug will fail.

Afflux:-In order to Neutralize the effect of artesian pressure we need to build a structure up to the height of artesian head above ground level. Building Well cap up to the height of artesian head above ground level will disturb the natural waterway thereby increasing afflux of bridge, which will require fresh design. Although, to neutralize the effect of both false Steining is considered as a effective solution by building false Steining up to the height of artesian head above ground level will neutralize the negative artesian pressure.

The afflux effect can be neutralized by providing , false Steining with thickness of 300 mm and 4 m height which can be dismantled at the designed top level of the well cap.

The well foundation design worked well for the four wells but due to sudden artesian pressure P5 bottom plug failed. We have not done false Stening in borehole (P5) because at the time of plugging there was no artesian pressure. During plugging artesian pressure rose, which was tough to differentiate that rate of increase in water is due to Bottom Plug or due to artesian pressure. So, At the time of plugging no safety measures were adopted to stop artesian. As a result, the soundness test failed due to artesian. This paper covers the literature at global level and the some case studies show the following solutions where the bottom plug or the deep foundation fails.

RESULT AND DESCUSSION

The well foundation design was successful for the four piers but due to sudden artesian pressure the well foundation for the fifth pier (P5), the bottom plug failed. We did not construct false Stening in the borehole (P5) because at the time of plugging there was no artesian pressure. During plugging artesian pressure increased suddenly, which was tough to differentiate that the rate of increase in water was due to Bottom Plug or due to artesian pressure. So, at the time of plugging no safety measures were adopted to stop the artesian. As a result, the soundness test failed due to artesian. This thesis covers the literature at the global level and some case studies show the following solutions where the bottom plug or the deep foundation fails. Construction of relief well to transfer artesian pressure and additional bottom plug (2-5 m3) can also be provided. This can resolve the problem.

Comparison between design for high artesian pressure well and low artesian pressure well The well foundation design is more challenging in the case where the high artesian pressure exists. The bed boiling solution is cost-effective. In the case of the low artesian condition, the design is less costly. Bed stability is achieved by minimizing the scour. The sufficient soil cushion is required to counter the higher artesian pressure while it is less costly where the pressure is on the lower side. The provision offalse steining is a must in lower pressure and this is an economic solution. Provide the steining of 300 mm to up to 4 m height to neutralize the afflux. The labor cost is lower for constructing the well foundation in the low-pressure area as the work is less complicated.

CONCLUSION

The case study presented here is the technical description of the practical problems faced while executing the well foundation design in India in artesian environment. The case of artesian pressure has not been studied so far.

- The false steiningis constructed to provide the stability to the bridge by keeping the well free from artesian head. However, in the case of high artesian head the protective structure is built up to the height of artesian head.
- We have been working on the site and have observed the failure of bottom plug in one well. All the precautions were taken at the time of construction. The artesian water level in the well was stable at the time of bottom plug construction but suddenly the water level started rising and finally the plug failed. We attempted to investigate the cause of the failure.
- We consulted all the seniors on the site. We also studied the literature available on the similar conditions. All the design considerations were added to the well foundation i.e. bed boiling, soil cushion thickness with the help of bore hole test all the details of strata were taken into consideration at the time of design stage and thus eliminating the upcoming shortcomings at the time of construction.
- It has transpired through the serious contemplation that some solutions to the failure of foundation under the artesian condition can be the construction of intermediate plug, increment in the plug volume from 2-5 cubic meter
- The construction of relief wells in the close vicinity is a good solution and it an relive the artesian pressure.
- Our research is an attempt to seriously find the cause of failure of well foundation. The well foundation is suitable for country like India since this is appropriate type of foundation for physical and economic reasons.
- The testing procedures need to be made reliable and economical. We got to train the technical manpower to avoid failure due to human errors.
- It is a unique experience for the reasons such as the artesian pressure was relatively high as compared with the normal bridge site. There was a concentrated artesian flow.
- We experienced uncontrolled artesian flow during the installation of false steining, which endangered the safety of the foundation, and this washed out the soil particles.

- The major flaws of existing old technique, which were responsible for the triggering artesian,
- were improper, irregular study and measurement of artesian head, insufficient false steining diameter and height. The design considerations were not there in deep foundation. The stability of water level showed that as result of false steining the safety factor was improved and closing the well by bottom plug.
- We improved the technique of construction under flowing artesian condition by concreting the structure, drilling the wooden piles and controlling the river water by constructing the cofferdam.

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