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Soil Around the Pier Below the Bed Level of the River

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Abstract

This study presents the evaluation of vertical and lateral loads acting on a bridge pier–pedestal system subjected to self-weight and vehicular loading. The pier, having a height of 25 m, a length of 20 m, and a thickness of 1 m, was found to carry a self-weight of 1200 t. When combined with a vehicular load of 2000 t, the total vertical load on the pier becomes 3200 t. Considering lateral force effects, 21.7% of the total load was applied as lateral load, resulting in 694 t acting over the full height and length of the pier. The pedestal supporting the pier, with dimensions 20 m × 20 m × 3 m, contributes an additional self-weight of 2880 t. Consequently, the combined load of the pier and pedestal amounts to 6080 t, producing a lateral load of 1319 t acting over a height of 20 m. Further, below 30 m from the riverbed level, the additional pedestal mass increases the total load to 10,400 t, resulting in a lateral load of 2257 t acting over 30 m height. The analysis highlights the significant influence of self-weight accumulation with depth on lateral load demand, emphasizing the importance of accurate load estimation for safe pier and foundation design.

Keywords: Bridge pier, foundation design, lateral load, load intensity, pedestal, self-weight, structural stability, vehicular load

INTRODUCTION

Bridge piers and pedestals constructed in riverbeds are subjected to a combination of vertical loads, lateral earth pressure, hydrostatic water pressure, and hydrodynamic forces due to flowing water. Accurate estimation of these forces is essential for ensuring structural stability and safety. In the present study, the total load intensity acting on the pier–pedestal system due to self-weight and superimposed loads is evaluated as 8.451 t/m². The depth of water in the river is considered to be 35 m, resulting in a hydrostatic water thrust of 35 t/m² acting laterally on the structure. An equivalent underground water thrust of the same magnitude is also considered due to submerged conditions [1–3].

Weight of pier = 25 m (height) × 20 m (length) × 1 m (thickness) × 24 = 1200 t
Load on pier due to vehicle = 2000 t
Hence, load on pier = 3200 t

Lateral load = 0.217 × 3200 = 694 t acting on a 25 m height and 20 m length of pier.
Hence, load intensity =694/(25 × 20) = 1.39 t/m²

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Weight of pedestal = 20 m (height) × 20 m (length) × 3 m (thickness) × 24 = 2880 t
Total load of pier + pedestal = 3200 + 2880 = 6080 t

Lateral load = 0.217 × 6080 = 1319 t acting on 20 m height and 20 m length
Hence, load intensity =1319/(20 × 20) = 3.30 t/m²

Below 30 m from the bed level of the river, weight of pedestal = 6080 + (30 × 20 × 3 × 24) = 6080 + 4320 = 10400 t

Lateral load = 0.217 × 10400 = 2257 t acting on a 30 m height and 20 m length of pedestal.
Hence, load intensity = 2257/(30 × 20) = 3.761 t/m^2

The velocity of river flow is estimated to be 1.2 times the water depth, resulting in a flow velocity of 42 m/s. The hydrodynamic thrust generated due to this velocity significantly contributes to the overall lateral load acting on the pier. When the thrust due to water pressure and flow velocity is combined with the structural load intensity, the total load intensity acting on the pier and pedestal system is obtained as 168.45 t/m². This combined loading scenario governs the design of the pier, pedestal, and foundation, highlighting the importance of considering hydraulic effects along with structural loads in river bridge design [4–7].

Hence, total load intensity for pier and pedestal = 1.39 + 330 + 3.761 = 8.451 t/m^2

Depth of water in the river = 35 m

Thrust of water = 35 t/m^2

Underground thrust of water = 35 t/m^2

Velocity of flow = 1.2 × 35 = 42 m/sec.

Thrust due to the velocity of flow $=\frac{1000 \times (42)^2}{19.62} = 90\ t/m^2$

Hence, total load intensity including thrust of water = 160 + 8.451 = 168.45 t/m^2

RESULTS AND ANALYSIS

The stability of the pier–pedestal system was evaluated by comparing the applied load intensity with the available strength of the surrounding soil at different depths below the riverbed. The average unit weight of surrounding soil was considered as 1.6 t/m³ for the top layer and 2.0 t/m³ for the bottom layer, resulting in an average soil strength of 328 t/m² at a depth of 30 m below the riverbed in dry conditions. In saturated conditions, a reduction of 50% in soil strength was assumed, yielding an available strength of approximately 168.45 t/m². Since the applied load intensity at this depth was equal to 168.45 t/m², no erosion or instability of the surrounding soil is expected [8–10].

At 40 m depth below the riverbed, the total load acting on the pier and pedestal was calculated as 11,840 t, producing a lateral load of 2,569 t. The corresponding total load intensity was found to be approximately 168 t/m². The soil strength at this depth, assuming a unit weight of 2.5 t/m³ and an angle of internal friction of 35°, was estimated as 1,365 t/m² in dry conditions and 683 t/m² in saturated conditions, both of which are significantly higher than the applied load intensity.

Similarly, at 50 m depth, the total load increased to 13,280 t, with a lateral load of 2,882 t. The resulting load intensity remained approximately 168 t/m², while the available soil strength in saturated conditions was 563 t/m², confirming adequate safety against erosion and failure.

The load at the foundation base, including the self-weight of the foundation and water thrust, was estimated as 9,931 t. Based on an available bearing capacity of 330 t/m², a foundation base size of 20 m × 2 m was found to be sufficient. Due to the heavy loading, a raft foundation supported by a 600 mm thick compacted sand layer and a 600 mm thick compacted stone layer is recommended to ensure long-term stability.

Strength of the surrounding soil around the pedestal, average unit weight of soil:

Topsoil, γ = 1.6 t/m^3

Bottom soil γ = 2 t/m^3

Average unit weight $= \frac{1.6 + 2}{2} = 1.80\ t/m^3$

Average $\phi = \frac{20^{\circ} + 30^{\circ}}{2} = 25^{\circ}$

Hence, the strength of soil surrounding the pedestal at 30 m below the bed level of the river (in dry state):

$q = 1.80 \times 30 \times \left[\frac{1+Sin25^{\circ}}{1-Sin25^{\circ}}\right]^2 = 54 \times \left[\frac{1.423}{0.577}\right]^2 = 54 \times 6.082 = 328$ t/m^2

In a saturated condition of soil, 50% strength is lost.

Hence, the available strength of the surrounding soil around the pedestal

$\frac{328}{2} = 164\ t/m^2 \approx 168.45$ t/m^2

Hence, okay. No erosion of soil will take place if the unit weight = 2 t/m^2.

Load intensity at 40 m depth below the bed level of the river:

6080 + (40 × 20 × 3 × 24) = 6080 + 5760 = 11840 t acting on a 40 m height and 20 m length of pedestal.

Lateral load = 0.217 × 11840 = 2569 t acting on a 40 m height pedestal and 20 m length, hence, load intensity.

$\frac{2569}{40 \times 20} = 3.212\ t/m^2$

Hence, total load intensity 160 + 1.39 + 3.30 + 3.212 = 168 t/m^2

Strength of soil at 40 m deep below the bed level of the river, taking $\gamma = 2.5$ t/m^3 $\phi = 35°$

In dry conditions,

$q = 2.5 \times 40 \times \left[\frac{1+Sin35^{\circ}}{1-Sin35^{\circ}}\right]^2 = 100 \times \left[\frac{1.574}{0.426}\right]^2 = 100$ x13.652 = 1365 t/m^2

In saturated state strength = 683 t/m^2 > 168 t/m^2
Hence, okay.

Strength of the surrounding soil around the pedestal below the bed level of the river at a depth of 50 m.

The weight of the pedestal is 50 m in height and 20 m in length. Weight = 50 × 20 × 3 × 24 = 7200 t

Total load due to pier and pedestal = 6080 + 7200 = 13280 t

Lateral load = 0.217 × 13280 = 2882 t acting on 50 m below the bed level of the river and 20 m in length

Load intensity $\frac{2882}{50\ x\ 20} = \frac{2882}{1000} = 2.88\ t/m^2$

Hence, the total load intensity, including the thrust of water
= 160+ 1.39 + 3.30 + 2.88 = 168 t/m^2

Strength of the surrounding soil around the pedestal, 50 m below the bed level of the river

$q = 2.5 \times 50 \times \left[\frac{1+Sin30^{o}}{1-Sin30^{o}}\right]^2 = 100 \times 9 = 1125$ t/m^2

In the saturated state, the strength of the surrounding soil = 563 t/m^2 > 168 t/m^2.

Hence, no erosion of the surrounding soil around the pedestal will take place. Load at foundation base: load of pier + pedestal = 6080 t

10% weight of the foundation, hence, the load at the foundation base $\frac{10}{100} \times 6080 = 608\ t$

Hence, load at foundation base = 6080 + 608 = 6688 t by knowing lateral load at foundation base, which gives load intensity and depth of foundation is found, and weight of structure below ground level is found and added to the top load to get load at the foundation base.

Since the load at the foundation base is 6688 t, and the available bearing capacity of the rocky strata soil at the foundation base = 330 t/m^2

Hence, the foundation base size required = $\frac{6688}{330} = 20.27\ m^2$

Since 160 t/m^2 total thrust of water is also acting, which produces additional load at the foundation base 160 × 20.27 = 3243 t

Hence, total load foundation base = 6688 + 3243 = 9931 t

Hence, the foundation base size required $= \frac{9931}{330} = 30\ m^2$

Lateral load at foundation base 0.217 × 9931 = 2155 t/m^2

Provide a strong foundation =0.047

Depth of foundation $D_f = \frac{2155}{2.5} \times 0.047 = 41\ meter$

$\left[\frac{1+Sin\varphi}{1-Sin\varphi}\right]^2 = 0.047,\ \varphi = 40^{\circ}$

Length of pedestal = 20 m

20 × x = 30

$x = \frac{30}{20} = 1.5\ m$ or 2 m

Hence, a 20 m × 2 m foundation base size and a raft foundation are needed. Since a heavy load, a strong foundation should be provided by providing a compact sand layer of 600 mm thick, and 600 mm thick compact stone particles should be provided on the foundation base.

In building, if 46.51 t/m^2 is the thrust of water, the cross-sectional area of column due to 46.51 t/m^2 water thrust = 46.51 × 4 m (height of bottom column) × 0.7 m (width of column). This will give additional load on the bottom column, and the cross-sectional area of the column will be found. Similarly, determine the foundation base size for a supposed load at the foundation base of 137 t and bearing capacity = 30 t/m^2.

$= \frac{137}{30} = 4.57\ m^2.$

Due to 46.51 t/m^2 thrust of water load at the foundation base = 46.51 × 4.57 = 212 t load at the foundation base due to thrust of water taken. Hence, load at foundation base = 137 + 212 = 349 t

Hence, lateral load = 0.217 × 349 = 76 t/m^2

Hence, load intensity = 76 t/m^2

Depth of foundation, $D_f = \frac{76}{1.85} \times 0.111$ = 4.55-meter depth of foundation needed, and available bearing capacity of soil at foundation base = 30 t/m^2.

Foundation base size = $\frac{349}{30} = 11.63\ m^2$. The foundation base size should be provided.

In Road

The road foundation was analyzed considering the combined effects of vehicular loading and thrust due to water pressure. The thrust of water acting on the road foundation was taken as 46.51 t/m². The vehicular load acting on the road was assumed as 70 t, distributed over an effective contact area of 3.5 m × 1.2 m, resulting in a load intensity of approximately 20 t/m². Hence, the total load intensity acting on the road foundation becomes 76.51 t/m². Based on the available bearing capacity of soil of 20 t/m², the required depth of foundation was estimated to be approximately 4.59 m.

The total load acting at the foundation base due to vehicular loading was calculated as 1,700 t. Accordingly, the required foundation base area was obtained as 85 m², which corresponds to a foundation width of approximately 4.72 m for a road length of 18 m. Considering the additional load due to water thrust, the load at the foundation base increased by 3,953 t. Thus, the total load acting at the foundation base became 5,653 t.

To safely support this combined load under the given soil bearing capacity, a larger foundation area was required. Based on bearing capacity considerations, a foundation width of approximately 15.7 m was initially obtained. However, by providing a strong composite foundation consisting of compacted sand layers and compacted stone particles, the required foundation width could be effectively reduced. Finally, a foundation width of 3.0 m was found to be adequate, and a practical width of 3.5 m is recommended to ensure safety and durability under combined vehicular and hydraulic loading conditions.

If 46.51 t/m^2 is the thrust of water. If the load on the road at the foundation base is 1700 t load intensity due to a vehicle, 20 t/m^2 from 3.5 m × 1.2 m = 70 t.

1 m^2 = 17 t/m^2

Hence, the depth of foundation is to be found for load intensity 20 + 46.51 = 76.51 t/m^2

$D_f = \frac{76.51}{1.85} \times 0.111$ = 4.59 meters, suppose available bearing capacity of soil = 20 t/m^2.

Load at the foundation base of the road due to the vehicle = 1700 t

Hence, the foundation base size $\frac{1700}{20} = 85\ m^2$

Hence, 18 × x = 85

Length of one long, x = 4.722-meter vehicle

Hence, a foundation width of 4.722 meters is to be provided.

Hence, the foundation base size = 85 m^2

Thrust of water = 46.51 t/m^2

Hence, due to the thrust of water load at the foundation base = 46.51 × 85 = 3953 t

Hence, total load at foundation base = due to vehicle + due to thrust of water = 1700 + 3953 = 5653 t

If possible, bearing capacity of soil = 20 t/m^2, the foundation base size required for the road

$= \frac{5653}{20} = 283\ m^2$

Hence, 18 m × x = 283

$x = \frac{283}{18} = 15.70$ meters since the width is very much more, hence, a strong foundation is needed, a compact sand layer, and compact stone particles are to be provided.

Strength of the composite material of the strong foundation

$= \frac{Sand\ layer + stone\ particles}{Underlaying}$

$= \frac{20 + 165 + 200}{3}$ =128t/m^2

Hence, foundation width $= \frac{5653}{128} = 44m^2$

Hence, 18 × x = 49

x = 3 meters, the foundation width is required. We can provide 3.5 meters.

CONCLUSION

The stability of bridge piers and deep pedestals is governed not only by the structural strength of the pier itself but also by the interaction between the foundation system and the surrounding soil. In the present study, the surrounding soil below the riverbed was evaluated against the total load intensity acting on the pier–pedestal system to ensure that erosion, excessive deformation, or loss of lateral support does not occur. The results demonstrate that the soil around the pier plays a crucial role in resisting lateral loads, water thrust, and overturning effects generated by self-weight, vehicular loading, and hydraulic forces.

Although the pedestal extends to a depth of 50 m below the riverbed, the presence of strong surrounding soil provides effective lateral confinement, which significantly enhances the stability of the pier. This confinement reduces the effective unsupported length of the pedestal and prevents buckling under combined axial and lateral loading. The comparison between applied load intensity and available soil strength at various depths confirmed that the surrounding soil possesses adequate strength even under saturated conditions, thereby ensuring safety against erosion and shear failure.

The analysis also highlights the importance of considering hydraulic effects such as water pressure and flow velocity in foundation design. When combined with structural loads, these forces govern the design of the pedestal and foundation system. Proper evaluation of soil parameters, including unit weight and angle of internal friction, is therefore essential for a realistic assessment of stability.

Overall, the study confirms that the soil surrounding the pier and pedestal below ground level acts as an integral component of the structural system. Adequate soil strength and confinement ensure that no buckling or instability occurs even at large embedment depths. Hence, careful assessment of soil–structure interaction is essential for the safe and durable design of bridge piers and deep foundations subjected to heavy vertical, lateral, and hydraulic loading.

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