Effect of Scour on Load Carry Capacity of Piles on Mat Bridge

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ABSTRACT

Critical scour effects on bridge performance helps to predict the bridge load carrying capacity and as a result, may help prevent unnecessary looses. Very few studies have been conducted on current condition of Albanian bridge especially on integrations between water, pile foundation and bridge structures. Most of highway bridges in western and center Albania are over shallow water, including small creeks, wetlands and marshes. A widely used design and construction procedure for these bridges is to have the bridge superstructure supported on pile bents. Albanian rivers have aggressive flow regime. During major flood events, the volume and velocity of flood waters can cause considerable scouring. As the load carry capacity of these pile bent vary inversely with the bent height, a scour in certain height will reduce its load carry capacity.

This paper analytically summarizes the effect of the scour on pile bent load carry capacity. Load carry capacity of piles is calculated analytically, only geotechnical data are taken from site tests. Site inspections on Mat bridge show that 19 from 32 pile bents have serious scour problems. Analysis results indicate that pile bents due to scouring height have loosed a load carry capacity varying from 17.64 to 32.11% of that designed.

Keywords: *Mat Bridge, Scour, Pile Bent, Pile Load Carry Capacity.*

INTRODUCTION

Scour is one of the greatest reason that leads to bridge failure. In the United States more than 60% of bridge failure happen due to scour [1]. Scour causes complex effects on bridge foundation and on the entire bridge structure. Pile foundation capacities are greatly reduced due to removal of material by scour, which affects the capacity and stability of the overall bridge system [2].

Mostly of studies have investigated the substructure and superstructure separately. There are a few cases where the effect of scour is analyzed entirely with bridge structure [2]. Analyzing the behavior of bridge due to scour is a very complex study, which is why most of researchers study the effect of scour on substructure and then predict the effect of that on superstructure. There has been done so much work on effect of scour on substructure. Mainly there's been investigated the load carry capacity of piles, buckling risk and additional moment on piles due to increasing water height as effect of scour [3-5].

This paper intends to give a general view of scour effect on pile load carry capacity. Mainly all the bridges build in the western Albania have their foundation as friction pile. The soil profile where these piles are constructed is generally river deposits, wetlands and marshes. As the soil profile is similar for this part of country a case study has been done. For this case study to analyze lost load carry capacities, Mat bridge has been selected. This bridge was build in 1979 and its foundations are friction piles. From a previous study 19 from its 32 pile bents have serious scour problems [6]. The height of scour on these piles vary from 0.5m to 4.5m. It is critical for the departments in charge to determine which bridges have serious scour problems. This study pretends to give a general indication to responsible departments how scour depth effect the load carry capacity of piles.

Bridge Description

Mat bridge was built in 1979 over Mat river as part of Lac – Shkoder national road and railway. It is located on Lezha district as shown in Fig.1. The bridge serves for double purpose, two lanes for automobile and one train lane. The bridge has 33 spans with a total length of 787m. It has 32 piers and two abutments. All the piers are fixed over pile caps [7]. There are 30 identical pile groups with 28 piles, 30cm in diameter, 18 of them are 12m and 10 of them are 10m in length, pier 1 to 30. Two pile groups have 8 piles 100cm in diameter and 12m in length, pier 31 to 32 as shown in Fig. 2. Superstructure of the bridge is made of two parts, one for automobile and one for train. The automobile part is made of four identical T-shaped, pin supported reinforced concrete beams. The train line part is made of four identical I-shaped reinforced concrete beams simply supported on four rollers.

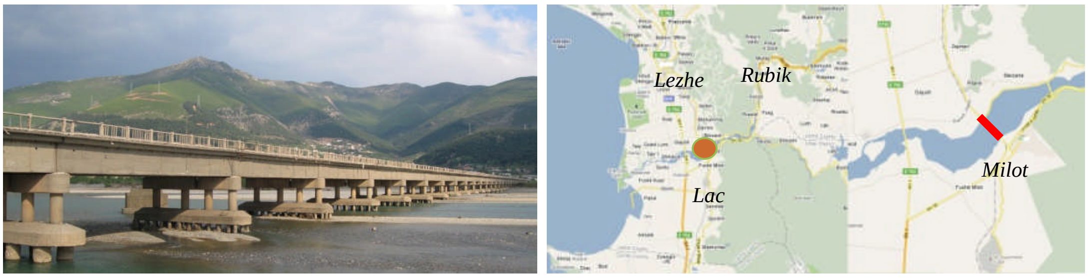


Figure 1. Mat bridge and its location

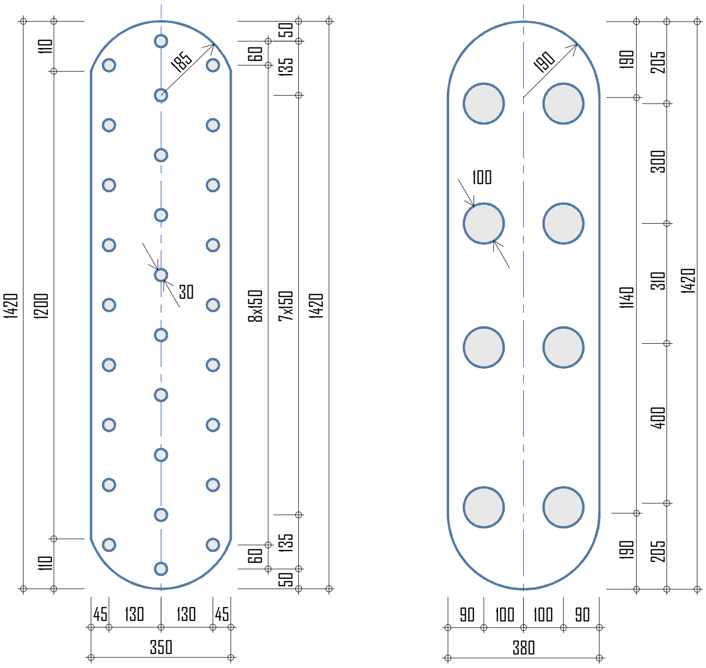


Figure 2. Pile cap view

The foundation's soil profile is made of four layers. First layer is 1.5m organic soil that do not have any load carry capacity, and in technical report it is specified that foundation should not be set on this layer [7]. Second layer is 3.5m low dense sandy gravel with unit weight γ = 18.2 kN/m^3 and angle of internal friction ϕ = 30^0. The pile cap is placed on this layer. Third layer is 6.0m medium dense sandy gravel with unit weight γ = 19.1 kN/m^3 and angle of internal friction ϕ = 32^0. Forth layer is more than 10.0m high dense sandy gravel with unit weight γ = 20.6 kN/m^3 and angle of internal friction ϕ = 35^0. End of piles are set on this layer. The foundation's profile of this bridge is shown in Fig. 3

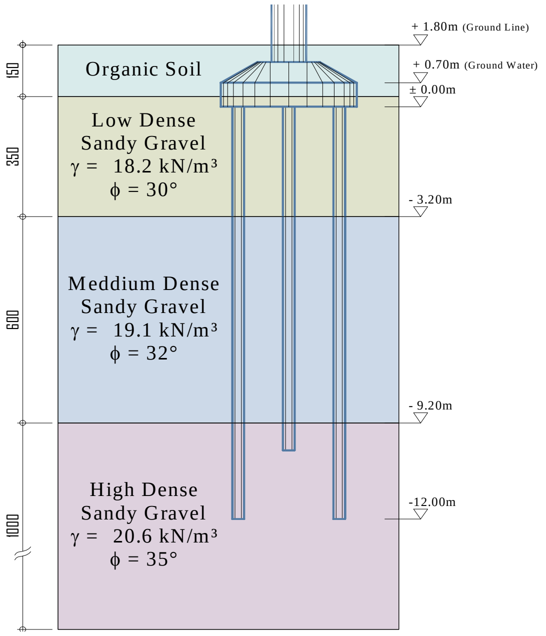


Figure 3. Soil profile and scoring view of pile group

ANALYSIS METHOD

In the design and analysis of piles, it is important to identify piles based on the nature of support provided by the surrounding soil, i.e. to classify piles as end-bearing piles and friction piles. While end-bearing piles transfer most of their loads to an end-bearing stratum, friction piles resist a significant portion of their loads via the skin friction developed along the surface of the piles. The behavior of friction piles mainly depends on the interaction between the surrounding soil and the pile shaft.

The ultimate axial load carrying capacity of the pile (Q_u) composed of the end-bearing capacity of the pile (Q_t) and the shaft friction capacity (Q_s). The general equation described in the literature is given as shown in Eq. 1.

$$Q_u = Q_t + Q_s = q_t A_t + f A_s \qquad (1)$$

where q_t is the unit tip bearing capacity, A_t is the area of the pile tip, f is the unit skin friction, and A_s is the area of the pile shaft. Depending upon the soil is loose sand, dense sand, normally consolidated clay or over consolidated clay, there are published relationships that depend upon the soil's engineering values for calculating ultimate axial load carrying capacity of the pile [8]. Soil profile where piles of Mat bridge are set is granular cohesionless soil. The unit skin friction resistance of cohesionless soil is calculated by *(β)* method. This method is based on coefficient of lateral soil pressure. Unit skin friction *(f)* is given by Eq. 2.

$$f = \sigma_v` K_s \tan(\delta) \qquad (2)$$

where σ_v` is vertical effective stress at measured point, K_s is coefficient of lateral soil pressure and δ is friction angle of soil versus pile.

For end bearing capacity Coyle and Costello's method is used. Coyle and Costello's is common method for cohesinoless soil and the unit end-bearing capacity is given by Eq. 3.

$$q_t = \sigma_v` N_q \qquad (3)$$

where σ_v` is vertical effective stress at measured point, N_q is bearing capacity factor.

Values of coefficient of lateral soil pressure *(K_s)* are taken from Tomilson, 1994 [9], values of friction angle of soil versus pile *(δ)* are taken from Kulhawy, 1984 [10] and values of bearing capacity factor *(N_q)* are taken from Prakash and Sharma, 1990 [11].

In granular soil the effective stress is equal to the difference between the total normal stress and the pressure of the water in a saturated soil. This relation is given in Eq.4.

$$\sigma_v` = (\gamma - \gamma_{water})h \qquad (4)$$

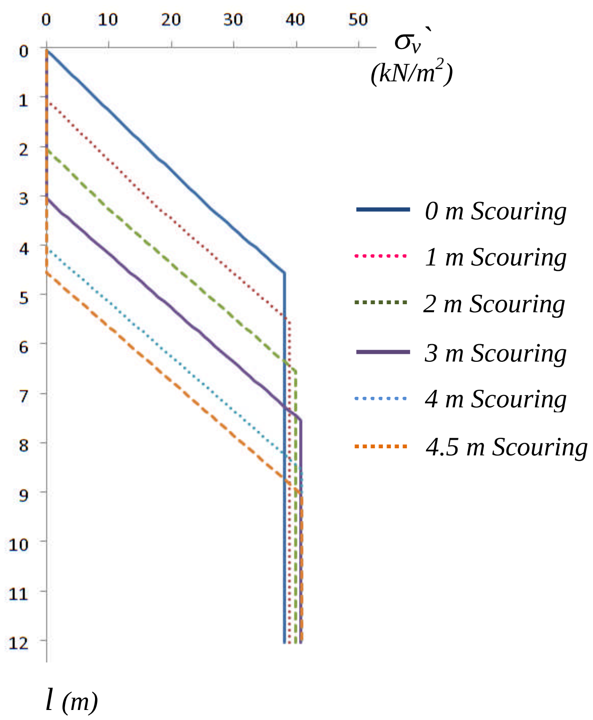
where γ is soil density, γ_{water} is the water density which for the calculations simplicity is taken as 10 kN/m^3 and h is the height of soil from measured point to ground level.

RESULTS

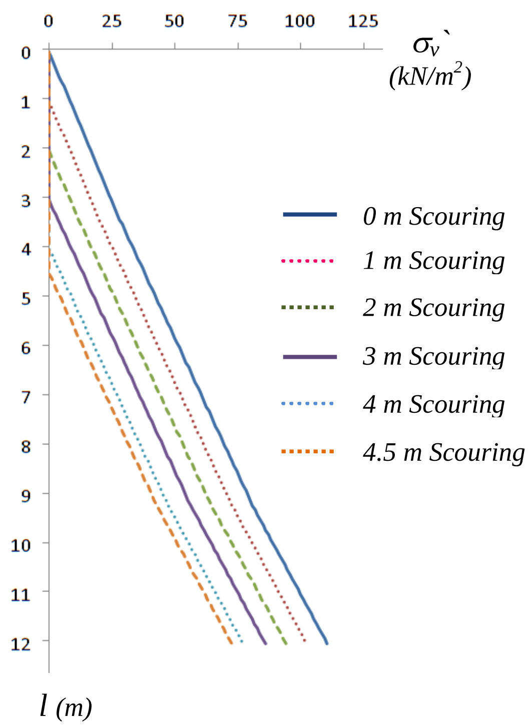
In literature it is accepted that effective soil pressure on piles increases linearly till 15D where D is diameter of pile, this length is known as critical depth, after that depth the effective soil pressure remains constant [8]. Based on Equation (4) the graphics of effective soil pressure among pile depth are presented on Fig. 4. Figure 4 (a) shows how the effective soil pressure is distributed along depth of piles with diameter 30cm. As shown effective soil pressure increase linearly till critical depth, and than it remains constant. Depending on scouring depth, that varies from 0 to 4.5m, which is the maximum scouring depth in bridge, effective soil pressure takes values shown. From 0 to 4.5m scouring the ultimate effective soil pressure takes values from 38.07 kN/m^2 to 40.95 kN/m^2. This increase in ultimate value by 2.88 kN/m^2 happens due to soil layers. As shown in Fig. 2 upper soil layers have lower density. Figure 4 (b) shows how the effective soil pressure is distributed along depth of piles with diameter 100cm. In those piles the critical depth is deeper than end of the pile, as a result the effective soil pressure increases linearly till pile end. From 0 to 4.5m scouring the ultimate effective soil pressure on 100cm diameter piles takes values from 110.53 kN/m^2 to 72.45 kN/m^2. The ultimate effective soil pressure in those piles is decreased by 38.08 kN/m^2 or 34.45%. Values of ultimate effective soil pressure and critical depth are presented on Table 1.

Table 1. Values of σ` and critical depth

		Scouring Depth (m)					
		0	1	2	3	4	4.5
30cm Diameter Piles	Ultimate σ` (kN/m^2)	38.07	38.97	39.87	40.77	40.95	40.9
	Critical Depth (m)	4.5	5.5	6.5	7.5	8.5	9.0
100cm Diameter Piles	Ultimate σ` (kN/m^2)	110.53	102.32	94.12	85.92	77.00	72.45
	Critical Depth (m)	15	16	17	18	19	19.5



(a)



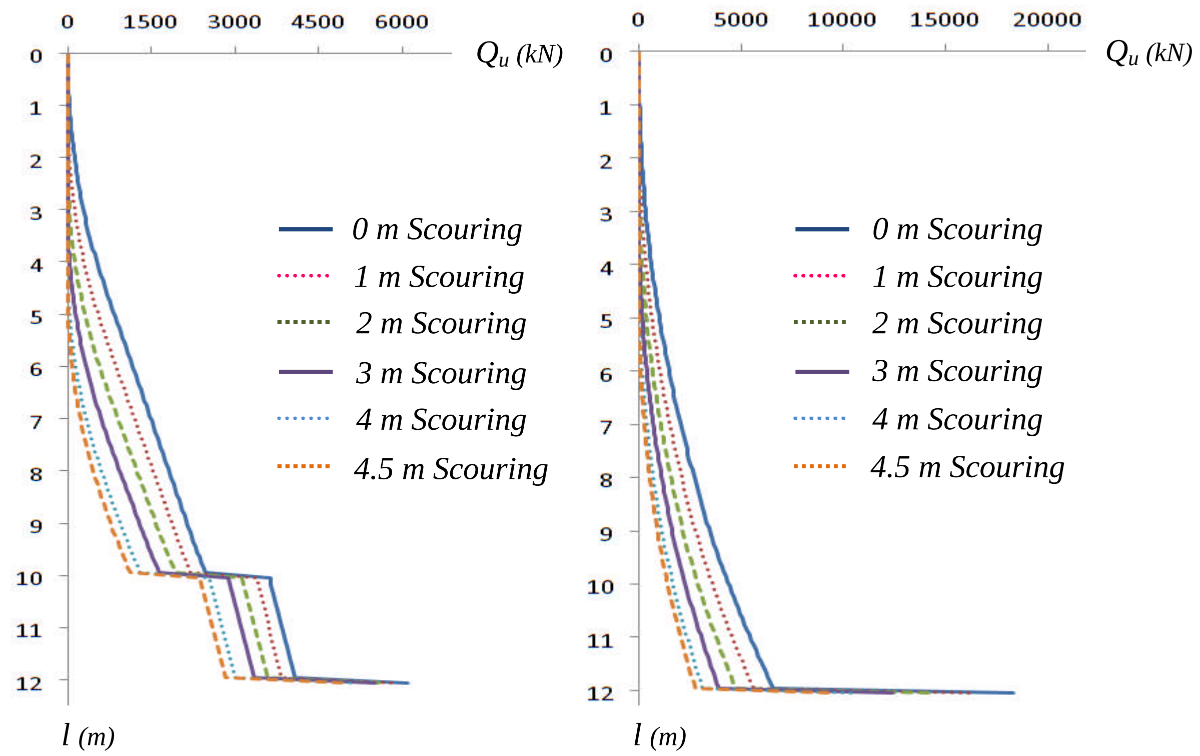
(b)

Figure 4. Effective soil pressure distribution, (a) 30cm diameter piles, (b) 100 cm diameter piles.

Based on equations (1), (2) and (3) and results shown on Figure (4) the bearing capacity of a single pile and group of piles is done. As shown in Figure (2) pile foundation is composed of pile groups. Prakash and Saran 1967 [12], have explained that for a distance between piles greater than 6D, where D is the diameter of pile, group do not have any effect. Sonmez and Ergun 1994 [13], have argued that piles that are set on granular soil mostly on sand have a group effect till the distance between piles is 3D, this effect reduces rapidly as the distance between piles goes from 3D to 4D, and there is no any group effect if the distance from piles is greater than 4D. In the case study piles have a distance from 3D to 5D so there is no any group effect. The ultimate pile group bearing capacity is the results of summation of individual piles.

Table 2. Ultimate bearing capacity and capacity loose of pile groups

		Scouring Depth (m)					
		0	1	2	3	4	4.5
30cm Diameter Piles	Ultimate Bearing Capacity(kN)	6101	5921	5729	5524	5200	5025
	Capacity Loose (kN)	0	180	372	577	901	1076
	Capacity Loose (%)	0	2.95	6.10	9.46	14.76	17.64
100cm Diameter Piles	Ultimate Bearing Capacity(kN)	18322	16281	14320	12438	10478	9513
	Capacity Loose (kN)	0	2041	4002	5884	7844	8809
	Capacity Loose (%)	0	11.14	21.84	32.11	42.81	48,08



(a) (b)

Figure 5. Bearing capacity of piles groups (a) 30cm diameter piles, (b) 100 cm diameter piles.

Numerical values of pile group bearing capacity are given in Table (2). The *0 Scouring* is taken as reference point for calculating looses in capacity. Loose in kN of bearing capacity shown in Table (2) is calculated as: *Bearing capacity (0m Scouring) – Bearing capacity (point scouring).* Loose in % of bearing capacity shown in Table (2) is calculated as: *[Bearing capacity (0m Scouring) – Bearing capacity (point scouring)]/ Bearing capacity (0m Scouring).*

Table (2) shows that the group of 28 piles, 30 cm in diameter, 18 of them are 12m and 10 of them are 10m can, carry a total load of 6101 kN. Figure (5) (a) shows graphically how the bearing capacity changes along pile depth. At level of 10m there is a shift on graph line, that horizontal line is end-bearing capacity of 10 piles. 30cm in diameter piles have two different depths, that is why graph shown in Figure (5) (a) has two horizontal lines. The horizontal line at 10m is what above is explained and horizontal line at 12m is the end bearing capacity of the rest 18 piles. Bearing capacity of these pile groups vary from 6101 kN at 0m scouring, to 5025 kN at 4.5m scouring. The reduction of pile group bearing capacity is approximately 17.64% at scouring depth of 4.5m.

Figure (5) (b) shows graphically how the bearing capacity of 100cm diameter pile group changes along pile depth. Numerical values of these pile groups are shown in Table (2). At 12m depth there is a horizontal line in Figure (5) (b) that shows the end-bearing capacity of pile group. 100cm diameter pile groups are composed of 8 identical 12m long piles. Bearing capacity of these pile group vary from 18322 kN at 0m scouring, to 9513 kN at 4.5m scouring. The reduction of pile group capacity is approximately 48.08%.

CONCLUSIONS

Assessment of scour on pile load carry capacity of Mat Bridge has been presented in this paper. Pile elements were analyzed analytically by the help of geotechnical data. The effects of different scour depth in pile load carry capacity were investigated. The depth of scour in Mat Bridge varies from 0.5m to 4.5m. The highest scour depth in 30 cm diameter pile is 4.5m, for this score depth there is a loose in load carry capacity of about 17.64%. The highest scour depth in 100 cm diameter pile is 3.0m, for this score depth there is a loose in load carry capacity of about 32.11%. Although the safety factors in soil mechanics vary from 2.5 to 3 the reduction in load carry capacity is considerable. Bearing capacity of pile effects directly the safety of entire bridge structure. Such looses in bearing capacity are serious risk for pier settlement or overturning as the effect of increased water pressure. It is suggested that these effects must be the subject of a further studies on deflection and bridge load carrying capacity.

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