Paper no- 150

Spacing of adjacent bridges based on local bridge scour and stress distribution in surrounding soil - A case study of New Kosi Railway Bridge between Katareah& Kursela Stations on Barauni Katihar Section (E.C.Rly), Bihar, India

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Abstract. Due to perpetual pressure on India's existing infrastructure, augmentation of road and rail infrastructure is need of the hour. Such developmental projects are invariably associated with construction of new bridges besides existing ones. While spacing of such bridges from existing ones is a crucial parameter which affects various operational issues and economy, it has to be decided by analysis of local scouring and geotechnical considerations. The development of the scour hole depends, among other factors, on sediment load, intensity of flow and characteristics of the channel. Presence of hydraulic structures like adjacent bridge pier affect sediment availability, flow intensity and sediment removal capability which affect development of scour. Stress distribution in the soil due to foundation pressure is another crucial aspect and adequate spacing between bridges is required to avoid overstressing. Lateral stability of foundations is ensured by adequate embedment or grip lengths. Lateral loads on bridges due to water pressure, eccentricity, flowing debris, vehicles etc is ultimately transferred to the adjoining soil by the bridge piers. Stressing of the adjoining soil due to lateral loads from adjacent bridges is another factor which affects spacing.

No clear guidelines are currently available to the engineers while planning new major bridges in the close vicinity of existing ones. This paper presents a case study of planning a new railway bridge for track doubling over river Kosi and analyses effects of local bridge scour, stress distribution in soil and stressing of adjoining soil in grip length, associated with adjacent bridges. The study may serve as guidelines for deciding adequate spacing of proposed major bridge(s) from existing ones which shall be helpful for various departments involved with planning & construction of new major Railway/Road bridges.

Keywords. Channel Flow; In-line piers; Local Bridge Scour; Stress Distribution; Bridge Spacing.

I. INTRODUCTION& OBJECTIVE

E.C. Railway has planned to construct a new Rail Bridge over river Kosi as a part of doubling between Katareah and Kursela stations on Barauni-Katihar section. The existing Rail bridge is 15 x 61.0 m Steel Open Web Girder (15 x 64.0 m c/c) with well foundation of 8m dia for single track. (Figure 1)

Due to perpetual pressure on existing rail/road infrastructure, authorities are taking up track doubling, planning new roads and railway lines while also developing fresh infrastructures to realize ambitious projects like Bharatmala Road Pariyojana, Golden quadrilateral NH network, Dedicated freight corridors &High-speed rail routes. Partly due to scarcity of preferable sites for major bridges, operational issues and primarily due to economic cost associated with detours(cost of land acquisition & approaches), new bridges are planned in the close vicinity of existing ones.

Estimation of local scour around bridge piers is an important consideration while deciding foundation level of bridge substructures. While an underestimation may lead to bridge failures by settlement, tilting, overturning, loss of grip etc. an overestimation leads to undue cost escalations. The local scour around bridge piers is a result of complex interaction of various parameters associated with the characteristics of sediment, bed material, flow, channel and geometry of piers. Estimation of scour for Rail as well as Road bridges has been based primarily on Lacey's regime theory. Lacey's scour formulae over simplifies the scour assessment using only design flood and silt factor. While recent researches in this field have proposed various formulae for scour estimation, the scour formula recommended by Melville (1997)which considers effect of pier geometry, characteristics of flow, armouring etc is being considered for adoption in codes.

Soil stress distribution is another guiding criterion for bridge foundations. The stress distribution from the foundations are primarily dependent upon sub-soil characteristics as well as characteristics of foundation itself. One of the most common methods for obtaining stress distribution is the Boussinesq (ca. 1885) equation based on the Theory of Elasticity. Boussinesq's equation considers a point load on the surface of a semi-infinite, homogeneous, isotropic, weightless, elastic half-space. Various methods are available, based on this equation, to estimate stress distribution below foundations. The stress distribution is vital to foundation settlement, stability and safety against shear failure. Thus, while planning bridges in the close vicinity of existing ones, the mutual interference/effect of adjacent bridge foundations need to be considered for working out optimal and safe spacing of foundations.

II. METHODOLOGY

The span configuration for the new railway bridge was kept same as the existing bridge and piers & abutments were proposed in line with the existing ones. The new bridge was proposed to be built on the upstream side considering approach track and land availability. To accommodate single track truss, the size of the foundations was worked out to be 8m dia wells for pier& abutment. The technical parameters of both the bridges are as follows:

Table 1: Existing & Proposed bridge parameters

S. No.	Parameters	Existing Bridge (from GAD)	Proposed Bridge
1	Span Configuration	15x61.0m(64.0m c/c) OWG	15x61.0m(64.0m c/c) OWG
2	Bridge Length	960 m	960 m
3	Dia of well	8.0 m	8.0 m
4	HFL	32.539 m RL	32.75m RL
5	LWL	24.422 m RL	24.422 m RL
6	Normal Scour Level	18.85 m RL	17.91 m RL
7	Max. Scour Level	5.10 m RL	0.8 m RL
8	Founding Level	-3.966 m RL	-13.0 (provided)
9	Grip Length	9.1 m	13.8m

Figure 1: Photographs of Existing Kosi rail bridge near Kursela in Bihar, India

Spacing between Existing & Proposed Bridges on well foundations

For finalization of the spacing between existing & the proposed bridge, three criteria have been considered as detailed below:

- Based on pressure bulb
- Based on passive resistance
- Based on scour

A. Based on pressure bulb:

Overstressing of underlying strata may lead to unanticipated settlements, localised failures leading to tilt and shift of foundations which are known to create operational and structural problems. In order to avoid problems related to overstressing of underlying strata, soil pressure zones below foundations having more than 10% of base pressure should not overlap i.e. $0.1q_0$isobars of adjacent wells should not overlap (q_0 is base pressure below footing). Various methods based on Boussinesq's equation commonly used to estimate stress distribution below foundations are available. A copy of pressure bulb based on Boussinesq's equation is shown below as **Figure 2**. The pressure bulb for circular shapes can be estimated by forming an equivalent square. Solutions of Boussinesq's equation for evenly loaded circular foundations can also be worked out and programmed for in depth analysis. However, considering diameter as the lateral dimension for estimation, with the pressure bulb below, gives slightly conservative results.

Minimum distance from center of well so that induced pressure is less than $0.1q_0$ is B. B can be taken as dia of the well which is 8m for proposed as well as existing well.

Thus the centre to centre spacing of wells works out to 16m (2*8m).

To avoid any effect on the foundation of existing bridge piers/abutments, while sinking of the new wells, a centre to centre safe distance of twice the lateral dimension of existing wells in the direction of shift is required so that the pressure bulbs of $0.1q_0$ of both the foundations do not overlap. Further, this distance shall also take care of requirement for construction of well and launching of girders.

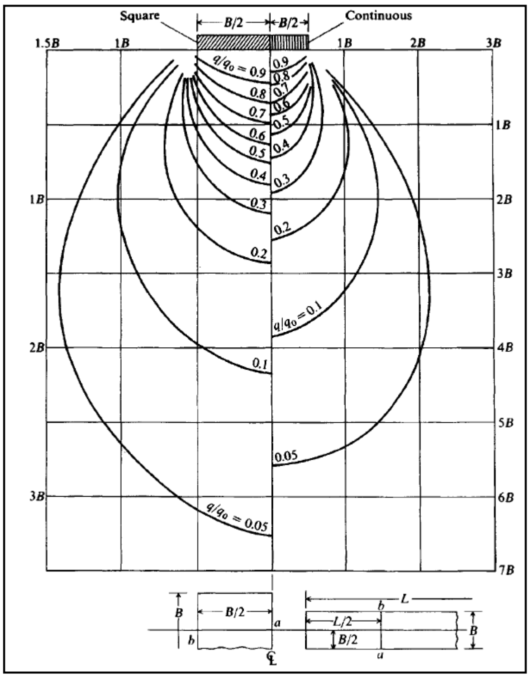

Figure 2: Pressure isobars (also called pressure bulbs) based on the Boussinesq equation for square and long footings. Applicable only along line ab from centre to edge of base.

B. Based on passive resistance:

Lateral stability of well foundations is attained through earth pressure from surrounding soils. Due to application of lateral loads (eccentric load, braking forces, water pressure etc) moments are generated which induce rotation tendency in the well. This tendency induces passive resistance from soil on one side which counters moments due to lateral loads. The passive resistance so induced should be sufficient to counter such moments and thus adequate grip lengths need be provided below anticipated scour level.

Proposed well should not interfere with the passive zone of the existing well and vice versa. Four cases need be considered based on tendencies of movement of adjacent wells on account of lateral loads:

i. Wells move away from each other: Passive zones are induced on upstream & downstream side of upstream & downstream wells respectively. Hence it's not a critical case.
ii. Wells move towards each other: Passive zones are induced in between and the soil is under compression. Hence it's not a critical case.
iii. Wells move in downstream direction: Downstream well may interfere with the passive zone of the upstream well. Thus clear spacing of Grip Length of upstream well x tan (45+Ø/2) should be available.
iv. Wells move in upstream direction: Upstream well may interfere with the passive zone of the downstream well. Thus clear spacing of Grip Length of downstream well x tan (45+Ø/2) should be available.

Thus as per passive resistance criteria, clear distance upto which soil will be affected from existing well/new well will be: maximum of Grip Length of either well x tan (45+Ø/2).

Based on the sub soil investigation carried out at the bridge site Ø = 33^{o} was estimated.

Approx. Grip length of existing bridge = 9.1 m
Grip length of proposed bridge = 13.8 m
Passive resistance zone between

proposed & existing well = maximum value of grip length of either wells X tan(45+ Ø/2)
=13.8 x tan (45^{o}+33^{o}/2)
= 25.42 m.

Accordingly, the centre to centre distance of wells works out to **33.4m** (8/2+25.42+8/2).

C. Based on Scour:

Mechanism of Scour:

The incoming flow near bridge pier transforms into system of vortices due to separation of flow. At the upstream front of pier down flow is induced which digs into the bed. The down flow turns at the scour hole and transforms into horseshoe vortex which carries the eroded material around the piers downstream. A system of shed vortices is generated alternately at the sides of the piers which suck the sediments from around the piers and carries them downstream. The scour development begins around the piers and travels upstream around the piers however deepest scour holes are generally observed at the front of pier. Equilibrium is reached as the scour hole develops and the vortices are no longer able to carry the sediment outside the scour hole.

Effect of adjacent pier:

Presence of piers of adjacent bridge may affect the scouring mechanism as below:

- During clear water scour, the eroded sediment from the upstream pier might increase sediment load around downstream pier.
- Depending upon spacing and arrangement of piers, the flow intensity may increase/decrease at the downstream pier.
- If downstream scour extent of upstream pier meets the upstream scour extent of downstream pier, the sediment removal capacity might increase leading to deeper scours at the upstream pier.
- Depending upon pier spacing the zone of shed vortices of upstream pier may interfere with the zone of horse shoe vortices of downstream pier.

Scour around a structure such as a pier or caisson takes the shape as shown in figure below considering range of recommendations in literature based on studies widely, both in the laboratory and in the field, a range of recommendations can be found in the literature.

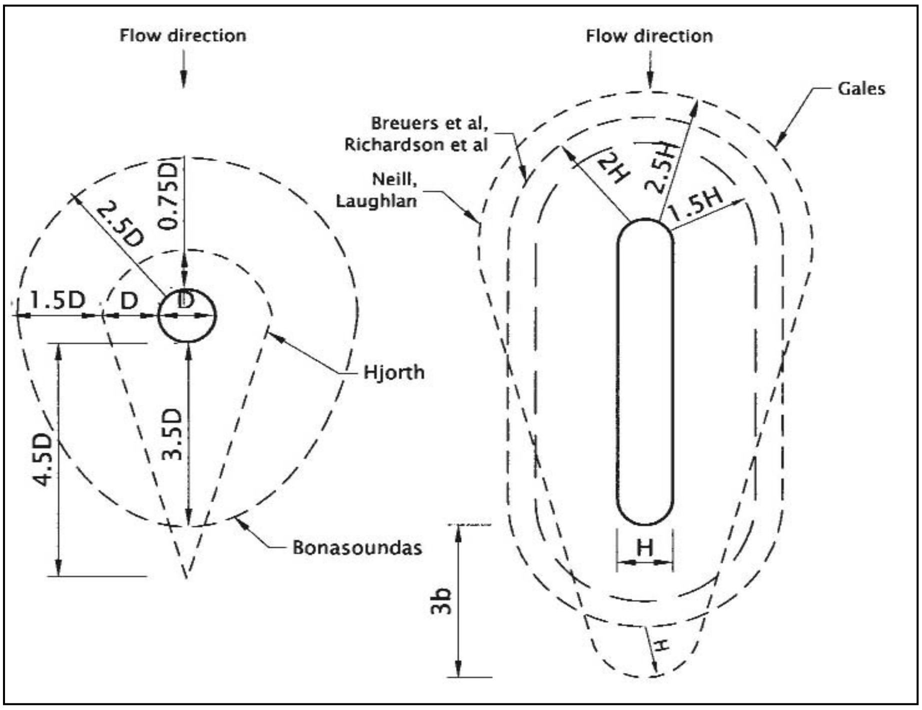

Figure 3: Alternate recommendations of Scour extent

Scour pattern by Bonasoundas (**Figure 3**) suggests scour hole propagation upto 3.5D in downstream and 2.5D in upstream direction for circular piers. Where D is diameter of well. In order to avoid overlap of scour holes of adjacent piers a minimum clear distance of 6D may be adopted. Therefore, distance works out to:

(i) Scour effect for proposed bridge in its downstream side = $3.5D_{proposed}$

$D_{proposed}$ = Dia of well of proposed bridge = 8.0m

Scour extent = 3.5*8.0 = 28.0m

(ii) Scour effect for existing bridge in its upstream side = $2.5D_{existing}$

$D_{existing}$ = Dia of well of existing bridge = 8.0m

Scour extent = 2.5*8.0 = 20.0m

Centre to centre distance between proposed & existing wells = 4+20.0+28.0+ 4 **= 56.0 m**

Another simplistic approach under the scour criterion was adopted using natural angle of repose of the river bed around the scour hole. Under this the extent of scour hole is worked out based on a scour hole slope of 2 : 1 around the well. The following hydraulic parameters were worked out for the bridges:

Scour affected area considering scouring slope 2:1 around well:

(i) for existing bridge: in upstream side = 2.0*13.68 = 27.36m

(ii) for proposed bridge: in downstream side = 2.0* 15.98 = 31.96m

Considering maximum value i.e. 31.96m,

Centre to centre distance between proposed & existing wells=4+31.96+4= 39.95m

say 40.0m

III. RESULTS AND DISCUSSION

Table 2: Summary of results

S. No.	Method	C/C Bridge spacing (m)	Adopted
1	Bulb Pressure ($0.1q_0$)	16.0 m	**Maximum of these = 56.0 m (adopted).** The maximum spacing of 56.0m required from scour consideration is adopted, which will satisfy the spacing requirement from other technical considerations also. The adopted spacing shall also provide adequate space for easy operation of machinery & equipments for construction of proposed bridge.
2	Passive Resistance Grip length x tan (45+Ø/2).	33.4 m	
3	Scour consideration		
	a) Scour affected area as per literature	56.0 m	
	b) Scour affected area as per general practices slope 2:1	40.0 m	

IV. CONCLUSION AND RECOMMENDATIONS

The new bridge was proposed to be built on the upstream side considering approach track and land availability. The span configuration for the new railway bridge was kept same as the existing bridge and piers & abutments were proposed in line with the existing ones to avoid flow concentration around downstream bridge piers. The effects of soil stress distribution, passive resistance and local scour around piers were analysed to finalize optimum& safe spacing of the bridges. The paper presents the case study for planning a new Rail Bridge over river Kosi as a part of doubling between Katareah and Kursela on Barauni-Katihar section of East Central Railway. Site photographs of the under-construction bridge is presented as Figure 4& 5.

The following may serve as guidelines for planning of adjacent rail/road bridges with in-line sub-structure arrangements.

1. Based on soil stress distribution criteria spacing should be such that isobars for $q \geq 0.1q_0$do not overlap to avoid over stressing of underlying strata. Detailed analysis in case of stratified soils shall be required.
2. Based on passive resistance criteria minimum clear spacing should be maximum of horizontal extent of passive zones created by either of the well foundation.
3. Based on local scour criteria the clear spacing should be such that scour holes of the adjacent piers do not meet. A minimum clear spacing of 6D for piers/well of same dia. and $3.5D_1 + 2.5D_2$ (D_1 : Diameter of upstream pier/well & D_2: diameter of downstream pier/well) for different diameter piers may be adopted.

Figure 4 : Proposed bridge (under construction) on upstream side of existing bridge. (View from Katareah end)

V. ACKNOWLEDGEMENT

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Figure 5:Proposed bridge (under construction) on upstream side of existing bridge. (View fromKursela end)

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