Distressed Railway Bridge No. 144 near Lailak-Mamalkha Railway Station, on Sahebganj Loop of Eastern Railway Bhagaipur District, Bihar

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Abstract

The more than hundred year old Railway Bridge over Sadonia River between railway stations Sabour and Lailak-Mamalkha, on Shahebganj Loop, Eastern Railway, was severely affected through settlement and subsidence of its right abutment (A1 abutment) and one of its four piers (P4), adjacent to left abutment since November 2007.This resulted in suspension of the train movement on this line from December 2007. Study of the available exploration data showed that the abutments and piers of the bridge are founded on a 10 to 11m thick silty clay layer having low competence (N value ranging from 4 to 9). This impervious silty-clay horizon is underlained by a saturated thick competent sandy horizon having N value ranging from 15 to 40. Deep widening cracks encircling the distressed abutment, subsidence cracks in two to three steps along both the banks of the river, sand boiling in the D/S of the bridge, seepage of water from the river bank etc. were noticed.

Distress in a bridge abutment and pier might have been caused by several factors such as a) scouring below the foundation level, b) plastic deformation of the foundation material, c) effect of swelling pressure of the foundation material, d) neotectonic activity/ earthquake/ any other man made ground tremor resulting in liquefaction of the founding soil, e) piping action below the abutment/pier foundations etc. After evaluating each of the probable causes vis-à-vis the available surface and subsurface data, it is concluded that the development of quick condition and piping through the foundation soil may be due to under high pore water pressure conditions and high hydraulic gradient due to the submergence of the area by the flood water of the nearby flowing River Ganges almost every year during the monsoon period.. The manifestation of the quick condition is seen in the form of occurrences of a number of sand boils and extensive bank subsidence along both the banks of Sadonia River covering a long stretch.

To restrict/confine settlement and lateral movement of the distressed right abutment Railway authority has initiated sheet piling encircling it. It has been indicated that selective sheet piling may cause destabilization of the rest of the piers and the abutment as the obstructed underground seepage may force its path below the foundation of the rest of the unprotected structures. Hence, it is suggested to sink a number of large diameter relief wells at about 20m intervals at least 3 to 4 meters into the underlying sand bed along both the banks of Sadonia river covering a 200m stretch at the upstream and downstream of the Bridge Axis. It has also been recommended that the sheet piles must go at least 3 to 4m into the underlying sand bed and that the sand boil zones must be loaded with reverse filter to prevent any further loss of material.

Introduction

The 50m long and 20m high Railway Bridge at Km 291/11-12 between Sabour and Lailak-Mamalkha stations on Sahebganj loop of Eastern Railway over Sadonia river (a tributary of Ganga), is a solid brick masonry structure constructed in 1903. The first signature of distressing of the right abutment was noticed in 1928 and after that in several occasions sinking and lateral shifting of the abutments was reported. Movement of trains through this bridge continued till 02-12-07 as the sinking and

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lateral movement of the right abutment and P4 pier was low. The continuous subsidence and alarming rapid lateral shifting of its right abutment compelled the Railway Authority to suspend the movement of the trains in this section from 02-12-2007. It was reported that up to 23rd November 2007, the settlement measured in the abutment was 97 mm and lateral shifting was about 300 mm. But between 23.11.2007 and 14.12.2007 the abutment has sunk further ~500 mm and has further laterally shifted towards D/S by about 700mm i.e. total lateral shifting of the right abutment till 14-12-07 was about 1000 mm.

In view of the old age and highly distressed condition of the existing bridge, the Railway Authority initiated soil investigation in this part. Salient observations which have been made through consultation of the soil investigation report are as follows.

1. Right abutment and P-4 Pier has been founded on clayey silt (CH group) at depths 4m and 8m respectively from the surface.
2. It is compressible in nature and can behave as a plastic material in saturated condition.

   As Natural Moisture Content (NMC) and the Plasticity Index (PI) is more or less same.
3. The thickness of this clayey silt unit varies from 5.5 m to 7.15 m in the riverbed and 10.50 m to 15.45 m towards the banks with 'N' value ranging from 4 to 9.
4. The underneath unit is a dense sand unit which is more than 12m thick with N value around 40.

To arrest lateral movement and sinking of the abutment Railway authority initiated rail piling encircling the distressed abutment. These rails are 8m of length. After observing movement within the driven rail piles they started steel sheet piling covering the rail piles and they decided to drive these steel sheets up to a depth of 12m.

Geomorphology, Geology & Seismicity of The Site

Geomorphologically the area lies on the older alluvial surface in the southern part of the Gangetic plain evolved mainly under the regime of the peninsular streams and has an overall northerly slope. But in and around the site, the river flows towards east indicating a local easterly slope of the landmass. The Sadonia River also flows from south to north from its origin and after taking a sharp easterly swing meets Ganges around 1km. downstream of the Bridge site.

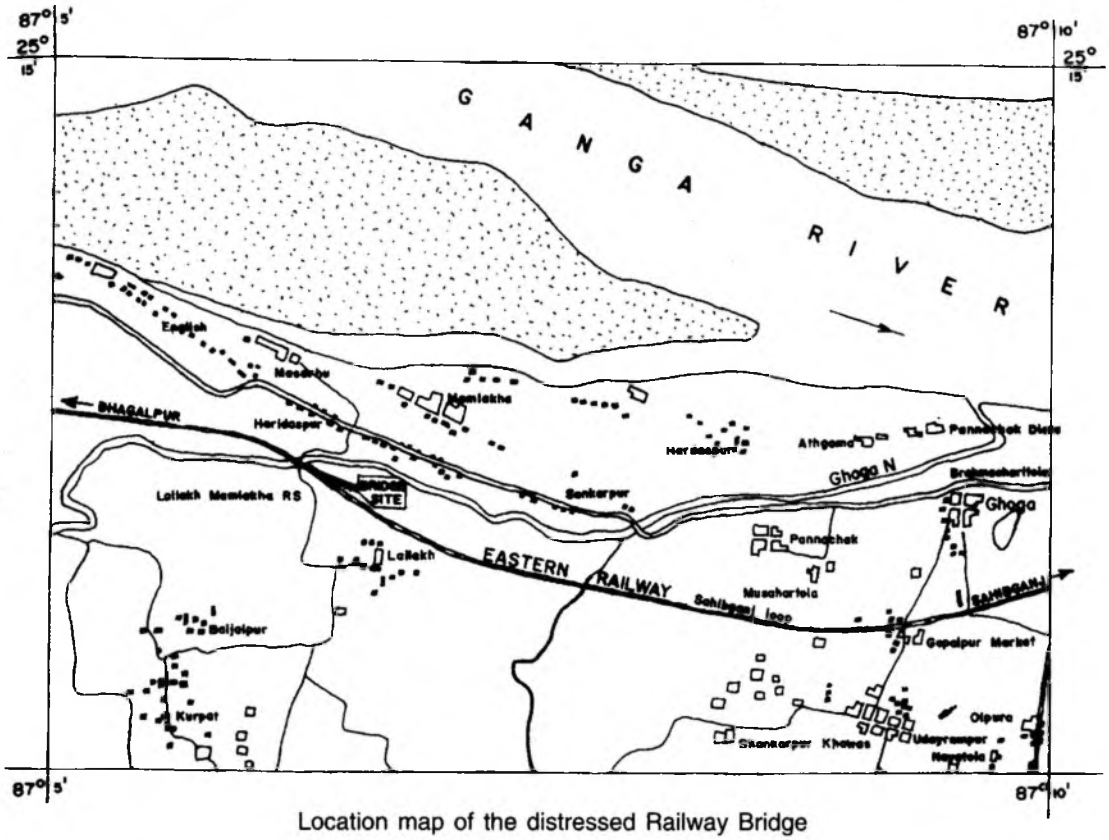
The Quaternary deposits of southern part of the Gangetic Flood Plan are broadly sub-divided into four units in the order of ageing. At the bridge site Belhar Formation (the third unit of this sequence) of Middle Holocene age, comprising alternate layers of unoxidised grey to feebly oxidized grayish yellow silty clay with ferruginous concretions and buff silt and sand are exposed.

The area falls in the Zone III of the Seismic Zonation Map of India. The epicenter of the 20th August 1988 (Bihar-Nepal Earthquake) of Richter magnitude 6.4 is located around 80km SW of the bridge site. The area felt an Intensity of VI-VII due to this earthquake. No major neotectonic faults are present in the vicinity of the distressed bridge site.

Site Condition

The right abutment and P-4 pier which is close to the left abutment have been affected by settlement and subsidence cracks. Due to this effect the rails got twisted and shifted towards downstream (Photo-1). The P-4 pier developed tensional cracks in the top part . However, no sign of subsidence or shifting of alignment was observed in P-4 pier. The cracks and fissures of the P-4 were repaired through grouting and after that no further deterioration has been noticed in P-4 pier. Gaping ground cracks and fissures were also noticed around the right abutment .

Highly distressed nature of the banks on both upstream and downstream of the distressed



Location map of the distressed Railway Bridge

bridge at least up to 500m D/S from the bridge axis was observed. Ground subsidences in two/three steps parallel to the river bank are also present in segments. These subsidence cracks have developed even ~30m to 50m away from the river edges. The ground subsidence is of the order of a few centimeters to more than 2 m while the width of the cracks ranges from 2cm to 50cm .

Striking observation is the occurrence of Sand Boils at a number of spots at around 200m to 250m downstream of the Bridge along the left bank of Sadonia river. Fine sand and silts ooze out along with water flowing to the river. In this part frequency and intensity of bank subsidence are more.

Soil samples of one completed bore hole (total depth 21m) adjacent to the distressed abutment were studied. The study revealed the following:

A) From 0m to 11m depth - Greyish yellow clay with an 'N' value ranging of 4 to 10.

B) From 10m to 11m depth – Blackish sticky clay with 'N' value of 4 to 10.

C) From 11m to 14m depth - Fine to very fine grayish sand containing quartz, mica, iron and opaque minerals with 'N' value of15 to 25.

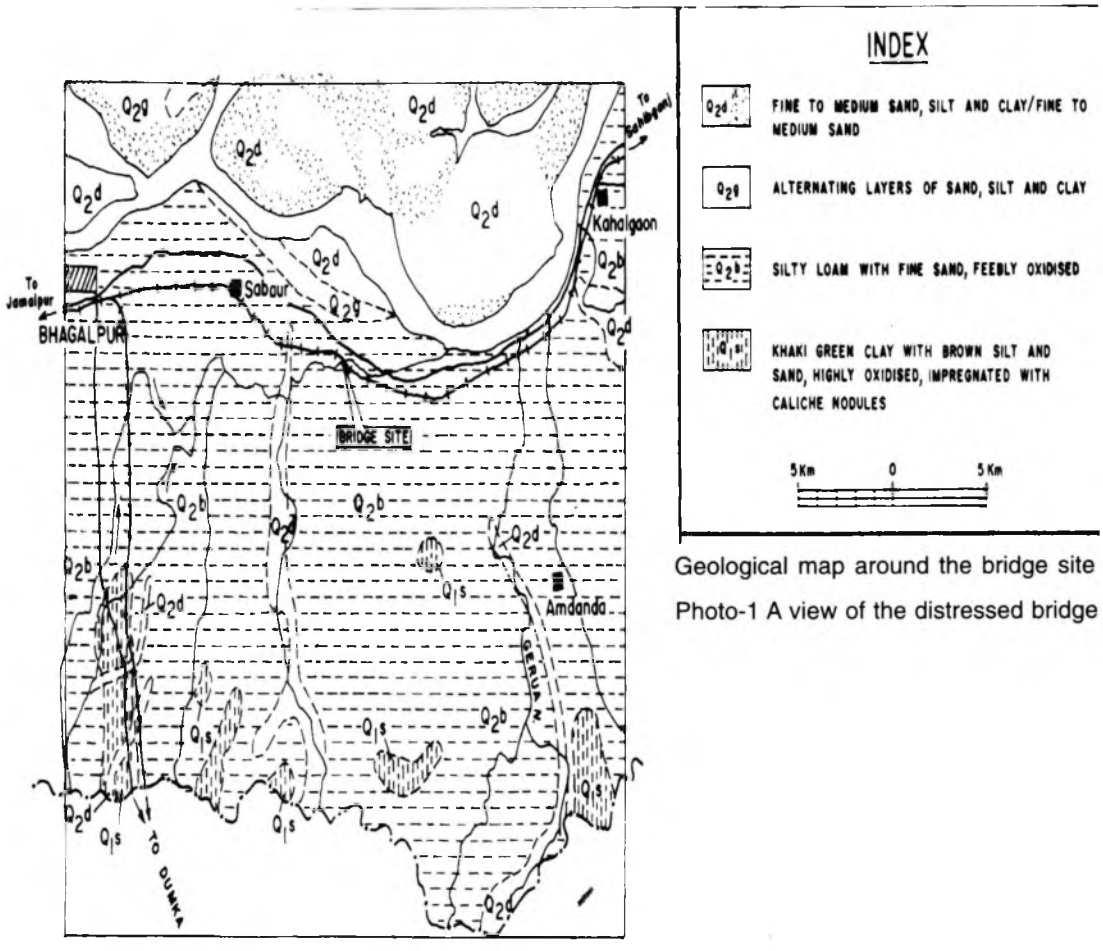
D) From 14m to 21m depth - Fine to medium grayish sand containing quartz, mica, iron and opaque minerals with 'N' value of15 to 40.

The analysis of the soil samples ascertained the following:

A. 0 to 11m depth— Clayey soil "CH class" having high plasticity.

B. 11m to 14m depth— Fine to very fine sand with considerable amount of silt and little quantity of clay.

C. 14m to 21m depth— Medium to fine grained sand with little quartz, mica, iron and opaque minerals.



Geological map around the bridge site

Photo-1 A view of the distressed bridge

The samples collected from Sand Boil locations comprise 50.95 %silt and 41.58 % very fine sand which resemble the fine sandy horizon at depth between 11m and 14m.

Petrological study of the clay minerals showed substantial amount of iillite, montmorrilonite and kaolinite with appreciable amount of quartz. Montmorrilonite in particular as also Illite possess swelling property when wet.

Geotechnical Discussion

Study of old reports revealed that the foundations for both abutments and piers have been founded on soil belonging to CH class with a very low bearing capacity having 'N' value ranging from 4 to 9, 2m below the estimated scouring depth.

From the critical evaluation of the geotechnical properties of the foundation material, five possible causes anticipated for the distressing of the bridge are evaluated. These are

a) Scouring below the foundation level of the P-4 Pier and right Abutment.

b) Plastic deformation of the foundation material.

c) Swelling of the foundation soil.

d) Piping action below the abutment foundation.

e) Neotectonic activity/ earthquake /any other artificial ground tremor resulting in sudden high pore water pressure giving rise to liquefaction of the foundation soil.

From the critical ground study no visible signature of scouring was noticed in any of the piers either in the river section or on the banks. Hence, scouring below the river does not appear to be the cause of distressing of the right abutment and the P-4 Pier.

The founding soil was probably in elastic stage of deformation under the influence of stress generated by the superincumbent static and dynamic load on the bridge when distressing of the right abutment in the form settlement was noticed since 1920's. In due course of time, the foundation soil might have undergone plastic deformation giving rise to the distressing of the bridge. But the undisturbed nature of the rest three Piers and left abutment does not indicate much support to this possible cause.

The founding soil contains substantial amount of illite and montmorrilonite with appreciable amount of kaolinite group of clay minerals. These clay minerals possess high swelling and thixotropic properties. Foundation failure due to swelling of clay when it comes into contact with water intermittently is a common phenomenon. In the present case, however, the foundation soil remains almost always in saturated condition due to very high ground water level. Hence, possibility of foundation failure due to swelling nature of the soil can also be ruled out.

The occurrences of Sand Boils may result either due to piping action or by liquefaction. Piping action is a common phenomenon in an alluvial terrain. Generally it is formed through a highly permeable foundation soil when an artificial hydraulic head is created through impounding of a reservoir. The high seepage force exceeding the critical hydraulic gradient initiates to erode out the foundation soil and appears as sand boils at favorable locales downstream. But, in the present case no reservoir exists in the vicinity of the distressed Bridge. The ground water table data reveals that it almost reaches near surface during the monsoon period when the area goes under submergence of the flood water. As the thick impervious top silty clay layer does not allow dissipation of seepage force in the underlying sandy aquifer, the possibility of occurrences of piping can not be ruled out.

Another cause of ground subsidence may be due to liquefaction of the founding soil. In general this mechanism of ground failure takes place during ground shaking either due to earthquake/neotectonic activity or artificially created vibration. The study of the Seismotectonic Atlas published by GSI does not indicate presence of any Active or Neotectonic Fault or Epicenter of any recent Earthquake in the vicinity of the distressed Bridge site. Hence, the probable cause of distressing of the bridge and bank failure due to liquefaction resulting from earth tremor can be ruled out. The only possibility for the development of liquefaction is the ground shaking caused by the train movement over the bridge. The other reason may be due to gradual chocking of the sandy aquifer by the overlying clayey material, resulting in the development of pore water pressure; coupled with vibration caused by train movement.

Occurrences of sand boils and ground subsidence may have resulted due to piping and quick sand condition caused by the super saturation of the founding soil having low N-value and high hydraulic gradient caused by

the flooding of the River Ganges. There may be some underground flow paths with high seepage force possibly below the right abutment and Pier-4, which are eroding the underlying supersaturated sand with the formation of some conduits. The top impervious10m to 11m thick clayey layer is not free draining. Thus, it does not permit relief of high pore water pressure and seepage force from the underlying sand horizon probably supporting the aquifer. At favorable locations where the thickness of this clayey zone has become less due to bank as well as channel erosion of the river bed ,this seepage force and pore water pressure are relieved off, piercing through the overlying silty clay layer. This may be one of the causes of failure of the right abutment and P4 pier. The characteristics of the particles are almost similar to that of the fine sand/silt zone present at 11m-14m depth. It indicates that piping is taking place from this zone .

Conclusions and Recommendations

On the basis of the foregoing geotechnical discussion the following conclusions and recommendations are made:

Conclusions

1. The more than 100 year old Bridge started showing sign of distress since 1928.
2. As reported by the Railway Authority both the abutments suffered some settlement intermittently prior to the maximum distressing in the year 2007.
3. Out of the four Piers, only P-4 Pier has been affected by subsidence cracks and slight tilting at its upper part.
4. The poor competency (low N value) of the founding impervious clayey soil strata, development of high pore pressure and high hydraulic gradient due to the submergence of the area almost every year during flood of the River Ganges, coupled with consistent ground shaking due to the movement of trains are responsible for the development of High pore water pressure and Quick Sand Condition. These are the main causative factors giving rise to the distressing of the right abutment and P4 pier of the bridge.
5. It is apprehended that the sheet piling, presently under progress, may cause destabilization of the rest three Piers and the left abutment if same measures are not provided there as the obstructed underground seepage force may find its path below the foundation of the unprotected components of the bridge.

Recommendations

1. The most appropriate remedial measure is to make necessary arrangement to relieve off the hydrostatic pressure by sinking two rows of large diameter Pressure Relief Wells initially at about 20m intervals along a 200m stretch both at the upstream and downstream from the Bridge site on both the banks. These wells should go at least three meters into the underlying sand horizon.
2. The sheet piles encircling the right abutment and P-4 Pier should penetrate at least 3m to 4m into the underlying sand bed.
3. The Sand Boil Zones should be loaded with reverse filter immediately to prevent any further flow of material.
4. The ground cracks should be filled up with sand mixed with coal tar.

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