REPORT NO: 28TH March 2011

REPORT ON

THE NH-57 AND RAILWAY BRIDGE OVER THE KOSI RIVER AT NIRMALI

Prepared by

MB VERMA

Former Distinguished Scientist DRDO
Program Director TEJAS LCA
Director ADA Bangalore
Email: mb_verma@rediffmail.com

COORDINATED BY

MGVP

Mithila Gram Vikas Parishad

Laxmisagar, South of Nanak Gas Godown,
Darbhanga – 846009, Bihar.
Email: mgvp91@gmail.com mgvpr@rediffmail.com
Phone/m: 9955344811, 06272-258085

PREFACE

The National Highway Authority of India has undertaken the construction of a bridge over the River Kosi on the NH-57 at Nirmali. The NH-57 connects Muzaffarpur to Forbesganj via Darbhanga and Jhanjharpur and is part of the East-West corridor. It passes through the flood plains of the river Kosi through a length of approximately 11km cutting across the Western and Eastern Embankments, at village Bhutaha and Bhaptiyahi respectively. The Indian Railways are also constructing one parallel Bridge over the River Kosi, 60 m downstream of the NH-57 Bridge, connecting Nirmali to Bhaptiyahi railway station.

The Bridge site selection, alignment, Hydraulic Design of waterway and River Appurtenances like the common Guide bunds, afflux cum protection embankments, physical model tests and computer model studies were done by CWPRS, Pune under the guidance of a Technical Committee under the Chairmanship of DG (RD & AS), Ministry of Road Transport and Highways/ Member (Technical), NHAI New Delhi. The Govt. of Bihar was represented in this Committee by Chief Engineer, Central Design Organization, Water Resources Department. Based on the tests and the studies conducted by CWPRS the waterway for both the Bridges were fixed as 1853 m and spread of Backwater and level of afflux upstream were estimated as 8 km and 1.35 m respectively at the Design Discharge of 22 375 cumecs (7.9 lac cusecs). However after completion of the Guide Bunds and Afflux cum Protection Embankments in the Kosi Flood Plains, and at about twenty percent of the Design Discharge of the River Kosi in the monsoon floods of the year 2010, the spread of the Backwater and Level of the Afflux far exceeded the predictions made by the CWPRS. This resulted in inundation of large number of villages upstream of the Bridge, affecting lives of nearly fifty thousand people. The eastern Afflux cum Protection Embankment, Guide Bunds and the NH-57 Bridge approach segment suffered breaches.

A Team of Engineers, as mentioned below went through CWPRS Reports, The Expert Committee Report and Minutes of Meetings of the Technical Committee on the NH-57 and Railway Bridge, and basic Design Assumptions made for the site selection and determination of the waterway, model preparation and testing.

This Team also went through Gokhul Prasad Expert Committee Recommendations on the NH-57and Railway Bridge over the River Kosi. They analyzed and deliberated upon the technical issues involved in the construction of the river training appurtenance. Some of the Team Members visited the Bridge Site, the affected villages and met the displaced persons taking shelter on the Kosi Eastern Embankment and spurs during the monsoon. They also visited the Bridge site and some of the villages in the month of November 2010, made observations of the damages and post flood Conditions of the river, both upstream and downstream of the bridge under construction.

This study revealed that in the estimation of the Design Discharge for 100- year Return Interval period for modeling of the bridge waterway as well as for selection of the site, there have been certain omissions and errors in of factual data. This resulted in the underestimation of the back water effect and the upstream river stage, causing breaches of the River Appurtenances, shoal formation, changes in downstream channels, sand deposition in arable land, and erosion of villages. Therefore there was a need for a Technical Audit and reappraisal of assumptions made in hydraulic and structural design of the Bridge and River appurtenances. This is urgently needed for ensuring the structural integrity of marginal embankments and for mitigating the sufferings of the people affected by the River Backwater and high Afflux between two embankments.

The under mentioned Engineers met at Patna on 28/3/2011 and deliberated on the above points.

1. Er Kuver Nath Lal
Former Engineer in Chief, Water Resources Deptt. Govt of Bihar

2. Er Shanti Nath Jha
Former Engineer in Chief, Water Resources Deptt. Bihar

3. Er. L K Das
Ex- Prof (SE). WALMI, Patna.

4. Er Chandra Shekhar Singh
Ex- SE, Water Resources Deptt. Govt of Bihar

5. Er Arun Prasad
Ex-SE, Water Resources Deptt. Govt of Bihar

6. Er M.G. Kauleshnam
Ex- Chief Eng, Water Resources Deptt. Govt of Bihar

7. Er BS Verma
Ex- Chief Eng, Water Resources Deptt. Govt of Bihar

8. Er SS Singh
Ex- Chief Eng, Water Resources Deptt. Govt of Bihar

9. Er. Jay Prakash Narayan
Ex-S.E. Water Resources Deptt. Govt of Bihar

10. MB Verma
Former distinguished Scientist, DRDO, Progm Director LCA

The Committee of Engineers mentioned above made the following recommendations:

1. The river training work in the Kosi should be undertaken where the channels bifurcate and should be joined there to flow as one channel.
2. The channels which have been plugged by construction of guide bunds and bridge approach roads should also be provided with bridge.
3. The main (unified) channel of Kosi should be regularly maintained so as to alleviate the sufferings of the people living between embankments of the river.
4. The villages affected by afflux should be protected so as to prevent the displacement of people. Provision should made for funding for this work by the Ministry of Railways and Road Transport.

The Committee considered the above as issues of Highest Public Interest and commended action by the concerned authorities of the Government of Bihar and Central Government.

THE NH-57 AND RAILWAY BRIDGE OVER THE RIVER KOSI AT NIRMALI

SYNOPSIS

The human intervention in the flood plains of the River Kosi downstream of the Bhimnagar-Hanumannagar Barrage by way of construction of the NH-57 and Railway Bridges, guide bunds and river training appurtenances like afflux and protection embankments, have initiated morph dynamic changes in the river behavior. In the process of construction of high afflux bunds cum protection embankments of the NH-57, four of the five channels were closed. As a consequence, the river channel courses were altered, affecting over fifty villages in Supaul district of Bihar. Some of these villages were affected by the afflux of back water of the bridge. With the rising stage of the river, the erosion of the homestead land and structures started, forcing eviction of the people even at modest river discharge of 4265 cumecs (150 600 cusec). The backwater spread as far as 15 km upstream of the Bridge in the village Siyani. The effect of Backwater and afflux would spread further when the flow reached the design discharge of 22 375 cumecs (7.9 lacs cusec), for the NH-57 and Railway Bridges. In the estimation of the Design Discharge for 100- year Return Interval period for modeling of the bridge waterway as well as for selection of the site, there have been certain errors of factual data. This resulted in the underestimation of the back water effect and the upstream river stage, causing breaches of the River Appurtenances, shoal formation, sand deposition in arable land, changes in downstream channels and erosion of villages. This warrants a review of technical assumptions and hydraulic and structural design of the Bridge.

1. INTRODUCTION

1.1 After completion of the 'Flood Control' element of the Kosi project work around 1964, nearly 380 villages, with total population of nearly 9.88 lacs (2001 census), spread over the districts of Supaul, Madhubani, Darbhanga and Saharsa were entrapped between the two embankments of the Kosi (Ref.1). It was envisaged at the planning stage that eastern and western embankments downstream of the barrage would be constructed maintaining certain minimum distance between them, so as to achieve channel flow stabilization and provide adequate flood plain area for the monsoons months. In some places embankments were kept as far apart as 15 Km (e.g. Supaul-Nirmali). Approximately 1.1 lacs hectares of land lies between these flood protections embankments. This land got permanently converted as flood plains of the Kosi. Over years sparse human habitation and seasonal agricultural work continued in the Kosi flood plains. Of late state sponsored major structural interventions have been made in flood plain of the river Kosi, of course all in the name of development, which altered the fluvial characteristics of the river, with wider ramifications on the physical and economic survival of the inhabitants between the two embankments. The construction of the bridge over the Kosi on National Highway-57(NH-57) is burning examples of the same. The river Kosi is jacketed to flow between two embankments, spaced approximately 11 km apart near Bhaptiyahi (located on the eastern embankment in Supaul district).

2. BRIDGE SITE

2.1 The bridge construction site lies between Km 37 and 38 downstream of the Bhimnagar Barrage. The NH-57 between Muzaffarpur and Forbesganj cuts across the river Kosi flood plain between its kilometer posts 155 to 165 near Bhutaha north of Nirmali. The NH-57 Bridge Head lies 525meter south of the river cross section 37 in the west, and 665 meter south of the river cross section 38 in the east, near Bhaptiyahi. The NH-57 then runs north along the Eastern Embankment for nearly 10km before turning east for Forbesganj. The Railway Bridge runs parallel to NH-57 Bridge, 60 meter down stream, at the same site.

3. WATERWAY AND RIVER APPURTENANCES

3.1 The Planners of the NH-57 and the Indian Railways have decided to provide only 1853 meters of the waterways for their respective bridges in the Kosi flood plain, with common guide bandhs, afflux and protection embankments. The total length of these additional river training structures in the river flood plain is approximately 10.1 Km and 10.5 Km on the left and right side respectively. The afflux cum protection embankments on both eastern and western ends of the bridge cut across two channels each in the flood plain of the river, stopping their flow and consequently increasing pressure on the main embankments.

4. PHYSICAL AND COMPUTER MODEL TESTS BY CWPRS, PUNE

4.1 The physical model testing and mathematical model studies of the bridge were conducted at the Central Water & Power Research Station (CWPRS), Pune. The waterways, common guide bund (i.e. inlet bund) for the bridge, afflux bunds and approach embankments across the river have been designed for discharge of 22 375 cumecs (7. 9 lac cusec) corresponding to 100 year return period, although the recorded less- than- 50 year peak annual discharge of the river was 25 856 cumecs (9 12 994 cusec) in the year 1968.

5. FLUVIAL BEHAVIOUR OF THE RIVER KOSI

5.1 With river discharge of 22 375 Cumec (7.9 lacs cusec), the model tests indicated an upstream afflux of 1.35 meter up to 8 km. But the ground reality was far-off this prediction. At the river discharge of 1 50 600 Cusec (4265 cumecs), recorded on the 17th August 2010 at 12:00 Hrs at the Kosi Barrage at Bhimnagar (photo 1&2), the afflux was over 3m and back water spread far upstream (photos 3&4).This caused heavy flooding of human habitations, deposition of sand in arable lands, and destruction of private and public properties (Photo 5, 6).Over thirty school buildings were rendered dysfunctional. The afflux bund cum protection embankment of the NH-57 on the left, which had blocked the flow of two secondary channels, breached downstream of Bhaptiyahi and was washed away in to the swirling current (Photo 7). This breach was enlarged to a length of nearly three kilometers. All attempts to plug this breach and stop the erosion were in vain till the end of monsoon. As a consequence of the breach of the afflux cum protection embankment, nearly four Km long eastern segment of the approach road of the NH 57 Bridge also got washed off into the River Kosi. This segment of the NH-57, constructed in the flood plains of the Kosi, had been washed away in the last monsoon too. Even after drainage of flood water downstream through this breach, the water level rose more than three meters high in the villages, which were located 15Km upstream of the bridge. One such example is the village Siani, 15 km away from the Bridge (Fig1). Here the rising backwater compelled inhabitants to leave their houses, carrying their thatched roofs on boats. The afflux level of upstream water, caused after construction of the afflux cum protection bunds on either side of the main channel was four to five times higher than the estimates made by the experts. As a result of this, water had entered the dwellings of the people, forcing their mass migration to higher places.

5.2 The residents of some of the villages between two embankments, taking shelter on the spurs, narrated that they didn't have to vacate their dwellings even in the 1968 floods, the year with the highest recorded flood discharge of 25 856 cumecs (9 12 994 cusec), which was more than six times the discharge of the Kosi in the monsoon of 2010. This was an indication of the quantum of the sedimentation of the river bed, presenting a classical case to River Engineers and Bridge hydraulics designers on the limitations of the mathematical modeling and prototype testing in the lab environment while conducting an assessment of the impact of the structural intervention in the flood plains of a river like the Kosi. The repeated furious attack of the River on structural interventions in her flood plain signified the inadequacy of the waterway of the bridge. The pressure of water would further increase as the river discharge increased to design level. Therefore imperatives of reviewing the design and taking corrective action could be ignored only at incalculable future cost.

6. STAND OF THE GOVERNMENT OF BIHAR

6.1 When it was clear from the CWPRS model tests and analysis that the afflux level of 1.35 meters up to 8 km upstream of the NH-57 Bridge site could be caused by the river condition of 22 375 cumecs (7 90 000 cusec) discharge, the Government of Bihar had asked both National Highway Authority of India (NHAI) and the Indian Railways in the year 2003 to review the design of the Bridge and increase the length of the waterway so that afflux level could be brought to zero. The CWPRS Pune had vide their letter JD/MSS/2003/7760, Dated 27.08.2003, addressed to CGM (EW) NHAI, New Delhi furnished the results of their mathematical model study which clearly indicated that for no afflux condition, the waterway of the bridge would have to be kept as 10.32 km. This meant almost bank to bank bridge over the Kosi. It was further evident from these parametric analyses at CWPRS Pune that with constricted river bridge design adopted by the NHAI and Railways Authorities, the adverse effect of upstream afflux on the villages couldn't be avoided. The fluvial characteristics of the river Kosi would change with long and high structures like guide bunds, afflux cum protection embankments and approach embankments erected in her flood plains.

6.2 An Expert Committee, constituted by the Government of Bihar, Water Resources Department in July 2004 under the chairmanship of Sri Gokhul Prasad, former Chairman Central Water Commission and two eminent retired Engineer - in – Chiefs of impeccable professional integrity and knowledge of the Kosi River as members of this committee, had advised the Government against construction of the afflux bunds cum protection embankments in the river flood plains (Ref 2). After examining the Technical Report of the proposed Rail and Road Bridge on the Kosi, this Expert Committee was of the view that the afflux bunds on both sides were likely to cause more problems. Further they had noted: **'**there are over 300 villages lying between the Eastern and Western Kosi embankments, where a sizable population live and carry out agricultural activities. This population is already aggrieved with the construction of embankment and the hardships faced by them during flood season could be well imagined. Some of these villages and cultivable land therein might be falling in the bridge and its backwater zone, which needs to be properly ascertained. The plight of these people is bound to be further aggravated with the afflux of 1.35 m. After extension of the afflux bunds, it would amount to providing a noose on their neck. It is apprehended that even during the lean season (non flood period), the backwater zone may keep cultivable lands and villages sub merged. As such there is urgent need of addressing this serious problem adequately.**'** The NHAI and the Indian Railways didn't pay any heed to the necessity of increasing the waterway of the bridge. They stuck to the Constricted Flow Bridge Design configuration with 1853 m waterways, and associated high Structural River Appurtenances like afflux cum protection embankments and approach road bunds in the river flood plains, Gokhul Prasad Committee had advised against. It was not clear why the Govt. of Bihar revised its above mentioned stand and what additional facts were at their disposal for doing so.

7. DEFICIENCIES IN BRIDGE SITE SELECTION

7.1 The bridge site selection at River Cross-Section 37/38 was recommended by CWPRS in the year 2002 based on the satellite imagery (1998 onwards) and topographic study. Approximately seven km upstream of this River Cross Section, the old railway bridge existed on the Nirmali- Bhaptiyahi route, which was washed away in the Kosi floods in the year 1938.The cubature study of the River Kosi after construction of the Bhimnagar Barrage indicated that the river bed level rise in the reach Dagmara- Supaul, through which the NH-57 Bridge passes, was (+) 18.6 mm per year as against the bed level degradation of (-) 0.083 mm per year in the upstream reach Bhimnagar-Dagmara, (Ref 3). Similarly, the volume change in the river bed in the Dagmara –Supaul reach was (+) 10.228 million metric cube per year as compared to (-) 1.181million metric cube in the Bhimnagar-Dagmara reach (Ref 3 *ibid*). This indicated that the present site of the NH-57 Bridge was not the ideal one from the point of view of the river bed sedimentation. The rate of aggradations of the river would further increase with construction of the river appurtenances like guide bunds, afflux cum protection bunds and bridge piers. The Expert Committee constituted by the Govt. of Bihar, under the Chairmanship of Mr. Gokhul Prasad for the NH-57 Bridge had advised that alternate sites should also be studied by the CWPRS for this Bridge, (Ref 2). This was not done. The selection of the present site, with high rate of sedimentation, would affect the structural integrity of the Kosi flood protection embankments. Further, it was contrary to the design objectives of long service life and structural integrity of the bridge.

8. BRIDGE SPACING AND WATERWAY REVIEW BY EXPERTS

8.1 The spacing of 60 m was provided between the NH-57 and the Railway Bridge, with the former located upstream of the later. The Expert Committee, under the Chairmanship of Shri Gokhul Prasad, had however felt that from the "strategic point of view the distance between rail and road bridges should be at least 400 m", (Ref 2, Para 2.1(ix)).

8.2 The effect of the river scouring on the Bridge was to be studied by model testing and analysis at CWPRS before freezing the design layout, as decided by the Technical Committee in their first meeting held on April 30, 2002.This study was not conducted and as such there was no data in the CWPRS reports regarding scouring depth of the piers of these bridges and their expected service life (Ref 2).

8.3 After the end of the first monsoon floods it was evident from the site visit that shoal formation had started within 20 m downstream of the Railway Bridge towards right bank, between two guide bunds.(Ref. Photo 8). The channel flow had skewed towards the left bank, down stream of the Railway Bridge, washing away parts of the eastern guide bunds (Ref Photo 9) and village Naua Bakhar further approximately 2 Km downstream. There was evidence of scouring of the NH-57 Bridge piers, upstream of the Railway Bridge, after the first monsoon floods (Ref. Photo 10).

8.4 Normally a braiding river, with high sediment flux like that of the Kosi,
starts forming sinusoidal dunes in flow direction with reducing discharge after the flood. If the pier of the Bridge at the selected site lies in the trough of the dune, the scouring of the pier is accelerated (Ref 3). The formation of shoals downstream of the Bridge and consequent change in the fluvial characteristics and behavior of the channel is continuation of this phenomenon. The physical model testing and the mathematical analyses are recommended with varying sediment load, slope and discharge of the river, both upstream and down stream of the proposed highway intersection, in order to predict pre and post structural intervention response of the

channel. The necessity for carrying out this study before finalizing the site and waterway of the Bridge was highlighted by experts in the Ganga Flood Control Commission (GFCC) too, whose views were communicated to NHAI and the Indian Railways by Sri Bhagwan Das, Chief Engineer, Central Design Organization, WRD, Bihar in his letter #923 dated 5 Aug 2003 as follows:

“The Chairman, GFCC pointed out that from the model test it appeared that the Approach Embankment to be constructed on both side of two proposed bridges which are extending into the course of the river and the waterway will be restricted to about 2Km. Even though this width may be adequate from the Lacey’s width point of view, still it will be prudent to study the behavior of the river after it comes out of the narrowed down passage in downstream areas”

8.5 The Technical imperatives for reconsidering the proposed waterway width of 1853 m as well as its impact on the morphology of the river and safety of the marginal embankments were again highlighted by the Chief Engineer, Central Design Organization, WRD, Bihar in his letter #1079 dated 1.09.2003 to GM (EW III), NHAI, New Delhi as follows: “----we have examined the matter regarding providing adequate waterway in the construction of proposed new bridge across river Kosi. Ganga Flood Control Commission has advised that apart from impact studies of the proposed bridge, it is necessary to get the impact assessment done downstream also. In this connection our examination of the issues has revealed that serious problem may arise both upstream and downstream of the bridges as in the case of the Road bridge over Ganges at Patna and the Road-cum –Rail bridge at Mokamah. Subsequent to our letter we have also found that in the proposed region of construction siltation is a very serious problem and as a consequence the freeboard of the embankment has already diminished subsequently. Hence, the broader base of the embankment has merged with the river bed and the top narrow portion now bears the brunt of pressure of flood water. As a result HG line has also shifted and become more obtuse. We are therefore, of the opinion that afflux upstream be kept at naught. This will call for redesigning the bridge to provide more waterways. This may somewhat push up the initial cost but result in saving crores of rupees in anti- erosion , flood fighting and relief work in future. The state is already facing serious consequences of post economics of design in construction all along river Ganges between Digha and Munger and Gandak at Dumariaghat”.

8.6 The Expert Committee under the Chairmanship of Gokhul Prasad had also recommended model study of the upstream and down stream impact of the proposed waterways by CWPRS before freezing the design options of the proposed Bridge (Ref.2). The constricted waterway design of the Bridge was favored by the Technical Committee principally for economic advantages such a design offers. Lacey’s Waterway equation for the Channel width as well as waterway lengths of the Bhimnagar Kosi Barrage, Dumarighat Bridge (on NH 107), Kursela Bridge (on NH 31) and Railway Bridge at Kursela over the River Kosi were considered by the Technical Committee as examples for technical justification for “capping length of 2000 meters” for the NH-57 and Railway Bridge at Nirmali (Ref 5). The Kosi Barrage has a width of 1148 m between the abutments. The upstream pond, expanding up to plains at Chatra, which is approximately 42 km away from the Barrage, has an approximate pond age area of 39 500 Hectare which cushions the flood as well as impounds the sediment. The river width upstream of the Barrage is 6940 meter, with afflux bunds on both banks. The pond level was designed for 6.09 m (Ref 6). In case of the NH-57 and the Rail Bridge over the River Kosi, the width of the River at the selected site was approx. 10 km. Further, upstream of the Bridge and between the eastern and western embankments, there is human habitation up to the Barrage in approximately 38 000 Hectare. Approximately sixty percent of this area is agricultural land (Ref 1). The Constricted Flow design of the Bridge at this site was likely to give rise to high level of afflux, affecting human population apart from its other ramifications discussed in subsequent paragraphs. Therefore the analogy of the shorter waterway provided for the Kosi Barrage was not applicable for the design of waterway of the NH-57 and the Railway Bridge at Nirmali.

8.7 The span of the Dumarighat Bridge over the River Kosi on the NH-107 was 963.4 m (not 900 m as informed to the Technical Committee and referred in the minutes of the third meeting, held on 20.12.2002, Ref 5). This Bridge was designed for river discharge of 19 900 cumecs. The comparison of waterway of Dumarighat Bridge with that of proposed NH- 57and the Railway Bridge was not appropriate, firstly because the Technical Committee had already accepted higher design discharge, i.e. 22 375 cumecs for the later Bridges. Secondly, the design of the waterway of the Dumarighat Bridge was itself inadequate because of the underestimation of the river discharge. At this river cross section, the River Kosi, apart from its own discharge from Bhimnagar Barrage carries the combined discharge of the Rivers Trijuga, Bihul, Bhutahi Balan, Kamla-Balan and Kareh (Bagmati) as well. Therefore the maximum (design) discharge of 19 900 cumecs for Dumarighat Bridge waterway design was gross under estimate. Subsequent events of scouring of foundation of five piers of this Bridge after less than 20 years of its service life, and their sinking down with modest river discharge of approximately 9900 cumecs in the monsoon of the year 2010 reveal the design deficiency of the Dumarighat Bridge waterway. The Technical Committee of the NH-57/ Railway Bridge put the cap on the waterway length of 2000 m for these Bridges, which was subsequently reduced to 1853 m, sighting an analogy which was not applicable. The geohydromorpho-dynamic conditions of the River, which prevailed at the time of washing away of the first railway bridge in Nirmali- Bhaptiyahi route (in the year 1938) and scouring of the piers of NH-107 Bridge in the year 2010, could offer valuable technical inputs for undertaking any future structural interventions in the flow of the Kosi.

8.8 The Lacey's equations for computing the width of the Bridge waterway, referred by the Technical Committee as well as GFCC are valid for a regime of stable channels in a state of dynamic equilibrium. There have been many improvements of the Lacey equations to define the regime channels (Ref 7). The River Kosi is unstable with high sediment load of varying grades in the regime. Even after it was embanked, its multi channels are constantly changing course within the confines of 10-15 km. In the River Cross Section 37/38, there were five channels of the River. Four of these channels were proposed to be plugged by constructing the afflux cum protection embankments of the NH-57. The Bridge was proposed over the fifth channel, which was also the main and central channel of the River. Therefore application of Lacey's equation for calculating the Bridge waterway for only one channel and ignoring remaining four channels of the River Kosi was of questionable merit.

9. REVIEW OF DESIGN DISCHARGE FOR THE BRIDGE

9.1 It was decided by the Technical Committee in their second meeting held on 23.10.2003 that since the Design Discharge adopted for the Kosi Barrage was 26 900 cumecs, this discharge should be adopted for the purpose of the foundation design of both the bridges As far as Design Discharge for the waterway was concerned, it was decided in this meeting that mathematical modeling should be done for discharge corresponding to 100- Year, 50- Year and normal flooding Return Intervals (RI) (Ref 8). The River Discharge for this RI was not specified. It was mentioned in the minutes of the third meeting of the Technical Committee held on 20.12.2002, "additional model runs with 100 year return period design discharge of 22 375 cusecs (cumecs) (7.9 lacs cfs) were taken up by CWPRS, which shows that the length of the bridge /waterway required is 2000 metres to avoid overtopping of flood embankments except at isolated locations" (Ref 5). The CWPRS was aware of the fact that the River Kosi had exceeded this discharge three times during last less than 50 years, i.e. during the year 1954,1968 and 1987 (Ref 9, *Para 4.9, Design Discharge*). Therefore the basis of arriving at discharge of 22 375 cumecs for 100- year RI for model testing and mathematical analysis is not clear.

9.2 The Kosi Barrage was designed and constructed in the 1950s and 1960s. Based on the analysis of the data available up to that time, the design discharge of 26 900 cumecs for the Barrage would have been arrived at. The highest discharge of the River, available at that time in records was 24 220 cumecs (8 55 226 cusecs), which had been reached during monsoon of the year 1954. In subsequent years, the River flood discharge had exceeded this record twice. It touched 25 856 cumecs (9 12 994 cusecs) in the year 1968, and 25 652 cumecs (9 05 791 cusecs) in the year 1987. The available data on the annual peak river discharge measured at Varahkshetra from the year 1947 to 2007 (total 61years), and the estimation of discharge for 100- year RI are placed as Annexure III and IV respectively. It could be noted that the discharge of 22 375 cumecs for RI of 100 years, which was presented to the Technical Committee and used by CWPRS Pune for physical model testing and mathematical simulation, was gross underestimation for the Bridge waterway design. Moreover the discharge for 100 years RI would always be higher than that for 50 years or less period of RI, unless the flood incidences of the year 1954, 1968 and 1987 are deliberately omitted from domain of flood frequency analysis. An independent study on "Flood Hazards of

North Bihar Rivers, Indo-Gangetic Plains", carried out by Sinha, Rajiv and Jain, Vikrant (Ref 10) put the River Kosi discharge for the RI of 100 years as 24 913.75 Cumecs at the Barrage. Therefore the physical model tests and mathematical analysis carried out at CWPRS based on River discharge of 22375 cumecs for 100-year RI wouldn't correctly reflect the river stage.

9.3 The under estimation of the design discharge would result in higher severity of the constriction of waterway of the Bridge. The 'Guide to Bridge Hydraulics' (Ref 11) states : 'In general, the more severe the constriction, the deeper will be the scour and required foundations, and the more expensive will be the channel control works. If the natural waterway is too severely constricted, the additional cost of the channel control works and future maintenance may exceed the savings on structure.' The breach of the eastern Afflux cum protection bund, Guide bunds and approach of NH-57 and onset of the pier scour of the Bridge at less than one third of the design discharge of the river in the last monsoon (year 2010) corroborate the above prophetic statements.

10. FLOW PROFILE IN THE INLET GUIDE BUNDS

10.1 During the physical model test at CWPRS, the right as well as left guide bunds was instrumented for measurement of flow velocities at ten critical locations along each bund. The channel width between the two guide bunds was 1917 m. It was found that at design discharge of 22 375 cumecs, the velocity was higher than 1.2 m/s at seven locations on the left and right banks each. The maximum velocity was 3.84 m/sec, observed at upstream inlet on the left guide bund. Similarly, on the exit end of the right guide bund, the velocity was found to be 3.18 m/sec (Ref 14, Table 3). The Erosion Threshold Velocity (Ve) is generally between 0.3 to 0.6 m/sec for fine sand to coarse sand bank material and 1.2 m/sec or higher for Clay as bank material in channel flow. Similarly the competent mean velocity for scouring of the piers of the Bridge in the flow depth of 1.5- 6 m for easily erodible material is 0.6-0.7m/sec. (Ref 15).The velocity measured during the model test in the lab were very high for the alluvial channel of the Kosi in the aforesaid flow depth range and conducive for the onset of scouring of the Bridge piers, bank avulsion and soil erosion downstream. With the present waterway of 1853 m, the severity of these parameters would further increase once the River discharge inched towards its previous records. The fluvial characteristic in the waterway guide channel is a function of the flow area, bed slope, material and sediment load and grade. The onset of shoal formation downstream of the Railway Bridge, scouring of the piers, and oblique and high exit velocity flow breaching the tail end of left guide bund, and erosion of houses in the Village Naua Bakhar 2km downstream were indication of serious design problem with the waterway.

10.2The Indian Railway Standard "Code of Practice for the Design of Substructures and Foundation of Bridges" (issued by RDSO, Lucknow), Para 4.2 Estimates of Design Discharge (Q), clause 4.2.2 stipulates: "All bridges shall be designed with adequate waterway for design discharge (Q). This shall normally be computed flood with a probable recurrence interval of 50 years. However, at the direction of Chief

Engineer/ Chief Bridge Engineer, bridges, the damage to which is likely to have severe consequences may be designed for floods with a probable recurrence interval of more than 50 years , while bridges on less important lines or sidings may be designed for floods with a probable recurrence interval of less than 50 years.” The waterway design for the bridge over the Kosi at Nirmali by ignoring the discharge levels of 1954,1968 and 1987, as explained in Para 9 above, were violation of the Railway Design Standards. Similarly Para 4.8 Clearance ‘C’ under clause 4.8.1 table of discharge in cumecs versus vertical clearance (mm) of this Standard lays down for “discharge above 3000 cumecs-vertical clearance 1800 mm”. The clearance ‘C’ has been defined in Para 2, clause2.3, as “the vertical distance between water level of the design discharge (Q) including afflux and the point on the bridge superstructure where the clearance is required to be measured. (Ref 16). The CWPRS was supplied the drawing by NHAI for model testing which specified this clearance, i.e. the difference between the HFL and the Soffit Level, as only 1000 mm (Ref 9, Para 3.3). Thus in correct data were used for the Bridge model testing; violating the Indian Railway Standard Code for the design of Bridges.

11. CONCLUSION

11.1 The Design Discharge of 22 375 cumecs (7 90 000 cusecs) of the River Kosi for Return Interval (RI) for 100-year is an under estimate. This needs to be re examined.

11.2 The gross waterway of 1853 meters for the Bridge (29spans@ 61m clear width plus 28 piers @ 3.0 m width), is inadequate even at the design discharge mentioned above. This should be reviewed.

11.3 The predictions of Backwater effect over a distance 8 km and afflux of 1.35 m at the Design Discharge of 22 375 cumecs, based on the physical model tests and mathematical analysis conducted at CWPRS were found not realistic. During the monsoon of the year 2010, even at about twenty percent of the Design Discharge of the waterway, the Backwater spread up to villages located 15 km upstream and afflux rose to approximately 5 m height, inundating several villages.

11.4 The River Kosi hydrologic data between the Barrage and the NH-57 Bridge site were gathered between pre and post monsoon months of 2002. The River bed and flood plain gradients, channel branching and Ana branching, locations and area of shoals, grading of sediments, bank slope and vegetation, and consequently the Manning’s ‘n’ have altered in the course of last 8 years. Therefore the accuracy as well as validity of data used by CWPRS Pune for Physical model preparation and testing as well as for establishing Gage –Discharge relationship at Bhaptiyahi and Dagmara, prediction of upstream river stage and topping of the segments of the eastern and western Kosi Embankment should be reviewed.

11.5 After due considerations, the Government of Bihar, Department Of Water Resources, had taken a stand that the back water effect up to 8km and the afflux level of 1.35 m were not acceptable. The afflux should be brought to zero. This had been communicated to the NHAI and the Railways. The CWPRS had then carried out further studies on their (NHAI-Railway's) advice and came out with the solution of having longer Waterway of 10320 m for the bridge in order to avoid backwater and afflux. The reasons for revision of the stand taken by the Government of Bihar and not choosing the option of longer waterway for the Bridge weren't clear.

11.6 The underestimation of the design discharge and the inadequate waterway for the Bridge at Dumarighat over the River Kosi on NH 107 led to scouring and collapse of five piers in less than 20 years of service of the Bridge. The Railways as well as NH-57 Bridges over the River Kosi at Nirmali are yet to be completed. Therefore taking cue from this failure as well as hydrologic conditions of the River during the course of last monsoon, design configurations of the Bridges should be reviewed.

MB VERMA

Former Distinguished Scientist DRDO
Program Director TEJAS LCA
Director ADA Bangalore
Email: mb_verma@rediffmail.com

LIST OF REFERENCES

1. Mishra, DK (2006), 'Kosi Nadi Ki Kahani, Dui Patatan Ke Bich Mein', Lok Vigyan Sanstha, Dehradun

2. Gokhul Prasad Expert Committee Report on Road and Rail Bridge On the River Kosi near Nirmali in Darbhanga Forbesganj Section of NH- 57 (2004), Govt. of Bihar Water Resources Department.

3. River Engineering for Highway Encroachments, Highway in the River Environment Hydraulic Design Series No. 6 (Dec 2001), USDT Federal Highway Administration, Publication N0. FHWA NHI 01- 004

4. Sanyal N. (1980) Effect of Embankment of River Kosi, proceedings of the International Workshop on Alluvial River Problems.

5. Minutes of the 3rd meeting of the Technical Committee on Rail-cum Road Bridge on River Kosi held on 20/12/2002 (Para 2, See annexure I for ready reference).

6. Galgali, V.G, River Training and Flood Regulation on the Kosi, 53rd Annual R&D Session CBIP.

7. Subramnya, K, (1997) Flow in open channels TATA McGraw Hill, page 506

8. Minutes of the 2nd meeting of the Technical Committee on Rail-cum Road Bridge on River Kosi held on 23/10/2002 (Para 2 and 3, see annexure II for ready reference).

9. Model Studies for Proposed Road and Rail Bridge on Kosi River, Niramali Bihar (March 2003), Central Water and Power Research Station Pune, River Engineering Lab Technical Report N0. 3982.

10. Sinha, Rajiv and Jain, Vikrant, (1998), Flood Hazards of North Bihar Rivers-Indo Gangetic Plains, Geological Society of India No. 41, 19981PP27-52.

11. Guide to Bridge Hydraulics (2004) Thomas Telford Publication, Transport Association of Canada

12. Govt of Bihar Jalsansadhan Bibhag, Letter No. 1090, Dated 11/09/2003 from Commissioner and Secretary to Member Technical NHAI New Delhi.

13. CWPRS Model Studies for the Proposed Twin Road Railway Bridge on River Kosi near Nirmali, N0. JD/MSS/2003/7760, Dated 27/08/2003

14. CWPRS Technical Report No. 4119 (June, 2004, Model Studies for extension of Guide Bunds of Proposed Road and Rail Bridges on Kosi River, Niramali, Bihar.

15. Bridge Hydraulics by Les Hamill E & FN Spon, UK

16. Code of Practice for design of structures of foundation of Bridge, Indian Railway Standard, RDSO, Lucknow.

Annexure I

Extract of minutes of the 3rd meeting of Technical Committee held on 20/12/2002 (Ref 5)

Para 2

“As decided during previous meeting, additional model runs with 100 year return period design discharge of 22375 cumecs (7.9 lacs cfs) were taken up by CWPRS, which shows that the length of the Bridge/ Waterway required is 2000 meters to avoid overtoping of flood embankments except at isolated locations.

The bridge length of 2000 meters suggested above was felt too long considering that the length of the existing road and rail bridges on the downstream of the proposed Kosi Bridge was reported as 900 meters only and they were functioning satisfactorily. The members were also of the opinion that keeping in view the aggrading nature of the river (in which shoals were reported to be appearing even at a discharge of 3 to 3.5 lac cuces), afflux and free board alone should not be the criteria for model analysis for deciding the waterway, since the scouring of river bed is likely to counter act the effect of afflux to a good extent,. It was also noted that the length of Kosi barrage is only 1150 meters, which is much less than the suggested waterway of 20000 meters. It was pointed out by the representative of CWPRS that bridge at the present location would be more affected by flash floods than the bridges at the downstream location with more stable/uniform flow conditions exiting there.

After prolonged deliberations, it was decided that physical model studies would be carried out for bridge length of 1200 meters, 1600 meters and 2000 meters keeping in view the flow and scouring pattern, flood pattern and afflux in the three dimensional model and the optimum bridge length/waterway would be decided based on the physical model analysis with a capping length of 2000 meters. It was also decided that the length and configuration of guide bunds for each of the above alternatives would be evolved based on the physical model studies and submitted along with report.

Action: CWPRS"

Annexure II

Extract of minutes of the 2nd meeting of Technical Committee held on 23/10/2002 (Ref 8)

Para 2

"The design discharge adopted for the Kosi barrage (width 1149m) is reported as 26900 cumecs. It was suggested by the Committee that this discharge may be adopted for the purpose to foundation design of both bridges and for deciding the spacing between the twin bridges, as recommended by CWPRS. Meanwhile, CWPRS would in its final report give detailed justification for the design discharge of 26 900cubicmetre per second along with a comparison of discharge data at the downstream locations (D/S of c/s 37&38) at Kursela and Dumarighat. The parameters for design of waterway, guide-bunds, approach embankment and other protective works for river training would be based on the design discharge of **100 year return** period.

Action: CWPRS/ANHI/Railways"

Para 3

"CWPRS have suggested a waterway of 2400m in their mathematical model study report. Considering the a aggrading behavior of the river, it was suggested that CWPRS would review the water way requirement after carrying out further mathematical model studies using the discharge of **100 year period** and corresponding afflux, spread of back water, level of existing flood embankments, guide bunds & other required river training works, along Kosi river, Model study would also be carried out for discharges corresponding to **norma**l flood conditions, **50 years** return period and **100 years** return period. The waterways adopted for the existing road bridges at Kursela, Dumarighat and Railway bridge at Kursela are also to be obtained from the respective authorities for comparison purpose. Modified mathematical model study report has to be submitted by CWPRS by the 3rd week of Nov. 2002 Action: CWPRS"

Annexure III
(Sheet 1 of 2)

Computation of Return Interval (RI) of Flood

Flow At Varahkshetra 1947 to 2007 in Cumec
(Calculation of Probability and mean return period(years))

Rank (m)	Year	Q_i (Flow in Cmec)	Probability (p(x)=m/n+1) (n= 61)	Periodicity (T= 1/p(x))	Q_m (Mean flow)
1	1968	25856	0.016129032	62	9746
2	1987	25652	0.032258065	31	9746
3	1954	24220	0.048387097	20.66666667	9746
4	1990	14429	0.064516129	15.5	9746
5	1970	13848	0.080645161	12.4	9746
6	1988	13421	0.096774194	10.33333333	9746
7	1948	13413	0.112903226	8.857142857	9746
8	1979	13344	0.129032258	7.75	9746
9	1984	13153	0.14516129	6.888888889	9746
10	1985	12942	0.161290323	6.2	9746
11	1974	12744	0.177419355	5.636363636	9746
12	1971	12178	0.193548387	5.166666667	9746
13	1949	11205	0.209677419	4.769230769	9746
14	1958	10563	0.225806452	4.428571429	9746
15	1962	10507	0.241935484	4.133333333	9746
16	1972	10484	0.258064516	3.875	9746
17	1988	10238	0.274193548	3.647058824	9746
18	1989	9964	0.290322581	3.444444444	9746
19	1950	9902	0.306451613	3.263157895	9746
20	1978	9830	0.322580645	3.1	9746
21	2002	9792	0.338709677	2.952380952	9746
22	1991	9360	0.35483871	2.818181818	9746
23	1975	9275	0.370967742	2.695652174	9746
24	1973	9203	0.387096774	2.583333333	9746
25	1976	9176	0.403225806	2.48	9746
26	2000	8935	0.419354839	2.384615385	9746
27	1998	8935	0.435483871	2.296296296	9746
28	1947	8845	0.451612903	2.214285714	9746
29	1967	8836	0.467741935	2.137931034	9746
30	1983	8819	0.483870968	2.066666667	9746
31	1952	8650	0.5	2	9746
32	1957	8580	0.516129032	1.9375	9746
33	1966	8553	0.532258065	1.878787879	9746
34	2001	8517	0.548387097	1.823529412	9746
35	2003	8498	0.564516129	1.771428571	9746
36	1961	8298	0.580645161	1.722222222	9746
37	1993	8196	0.596774194	1.675675676	9746
38	1969	8128	0.612903226	1.631578947	9746

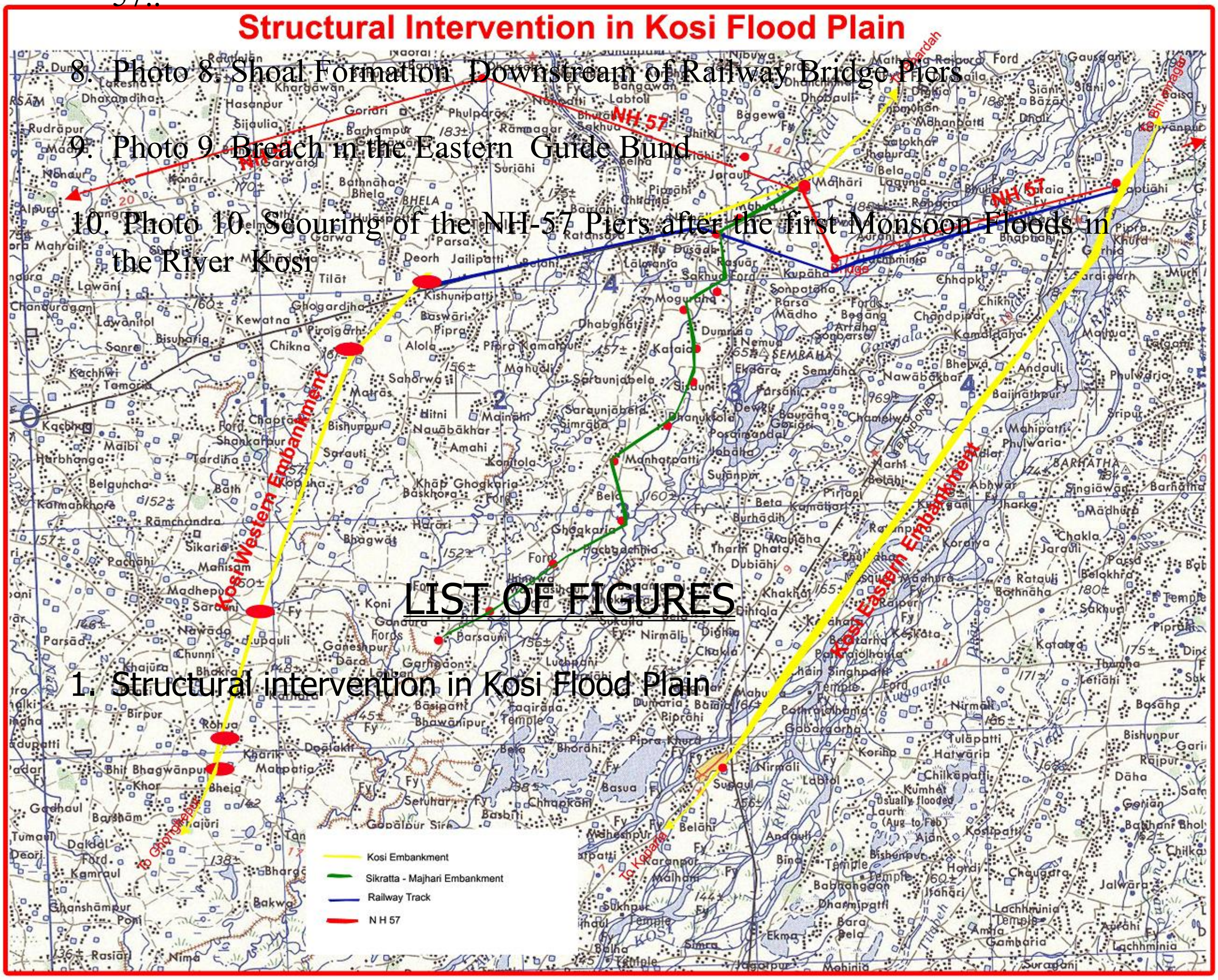
39	2004	8111	0.629032258	1.58974359	9746
40	1997	8070	0.64516129	1.55	9746
41	1981	7991	0.661290323	1.512195122	9746
42	1977	7778	0.677419355	1.476190476	9746
43	1980	7706	0.693548387	1.441860465	9746
44	1963	7646	0.709677419	1.409090909	9746
45	1995	7576	0.725806452	1.377777778	9746
46	1957	7533	0.741935484	1.347826087	9746
47	1986	7360	0.758064516	1.319148936	9746
48	1951	7257	0.774193548	1.291666667	9746

Annexure III
(Sheet 2 of 2)

49	2007	7252	0.790322581	1.265306122	9746
50	1955	7080	0.806451613	1.24	9746
51	1982	6970	0.822580645	1.215686275	9746
52	1994	6896	0.838709677	1.192307692	9746
53	1992	6896	0.85483871	1.169811321	9746
54	2005	6648	0.870967742	1.148148148	9746
55	1960	6627	0.887096774	1.127272727	9746
56	1959	5976	0.903225806	1.107142857	9746
57	1965	5749	0.919354839	1.087719298	9746
58	1964	5706	0.935483871	1.068965517	9746
59	1956	5437	0.951612903	1.050847458	9746
60	1953	5421	0.967741935	1.033333333	9746
61	2006	4305	0.983870968	1.016393443	9746
	Total	**594480**			

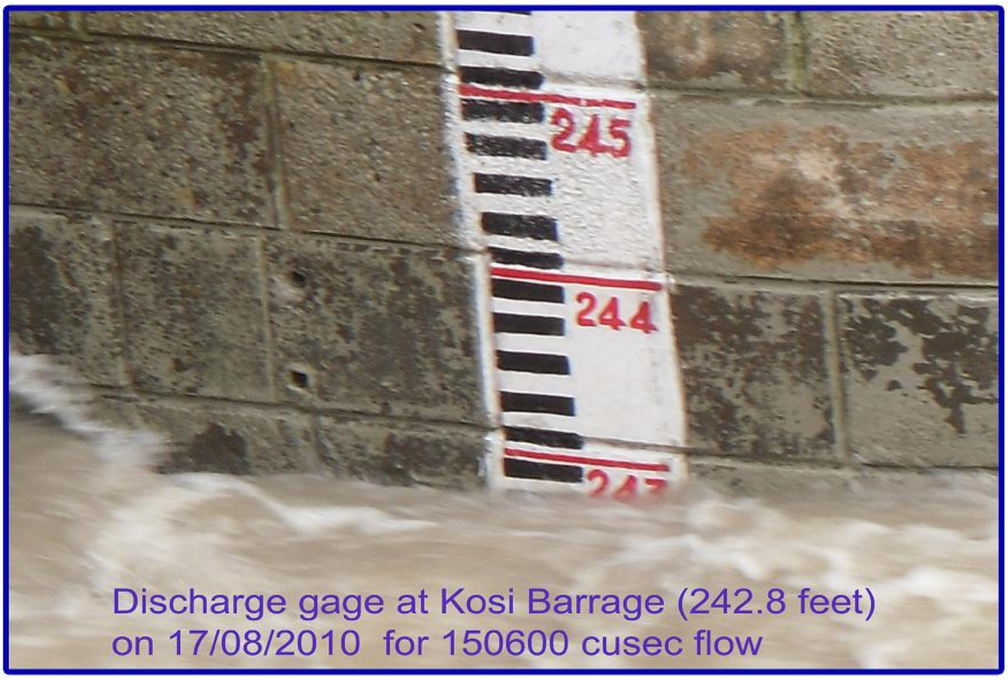
Annexure IV

LIST OF PHOTOGRAPHS



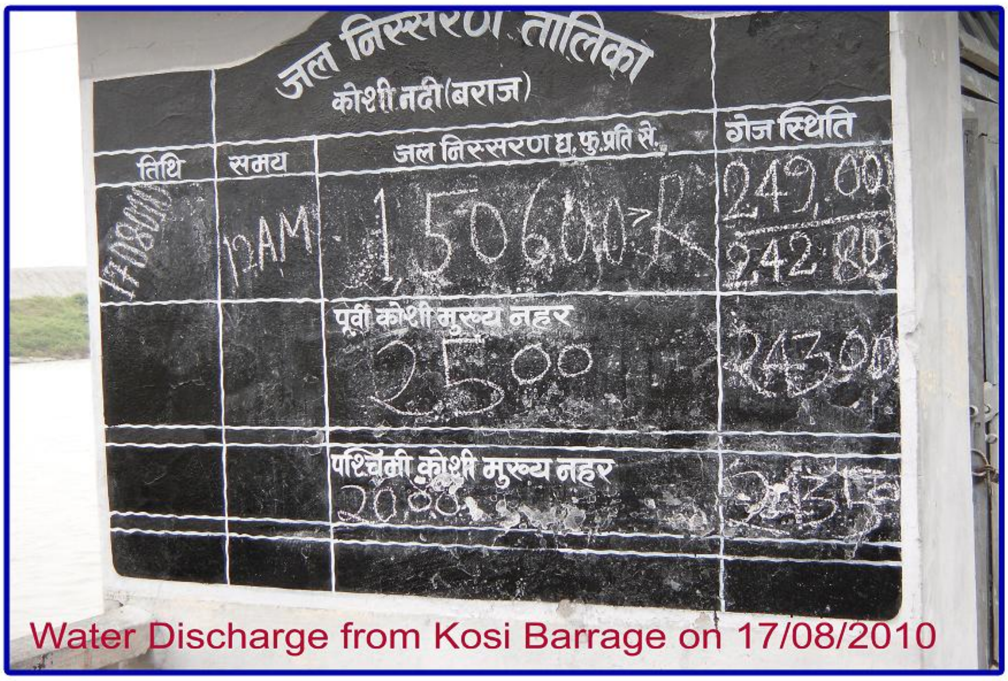
LIST OF FIGURES

Figure - 1



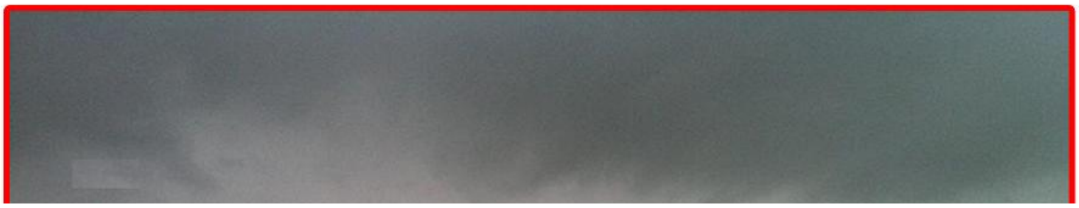
Discharge gage at Kosi Barrage (242.8 feet)
on 17/08/2010 for 150600 cusec flow

Photo 1. The River Kosi Discharge Gage Reading at
Bhimnagar Barrage on 17.08 2010 at 1200 Hrs.



Water Discharge from Kosi Barrage on 17/08/2010

Photo 2. River Discharge Display Board at
Bhimnagar Barrage on 17.08 on 17.08.2010.



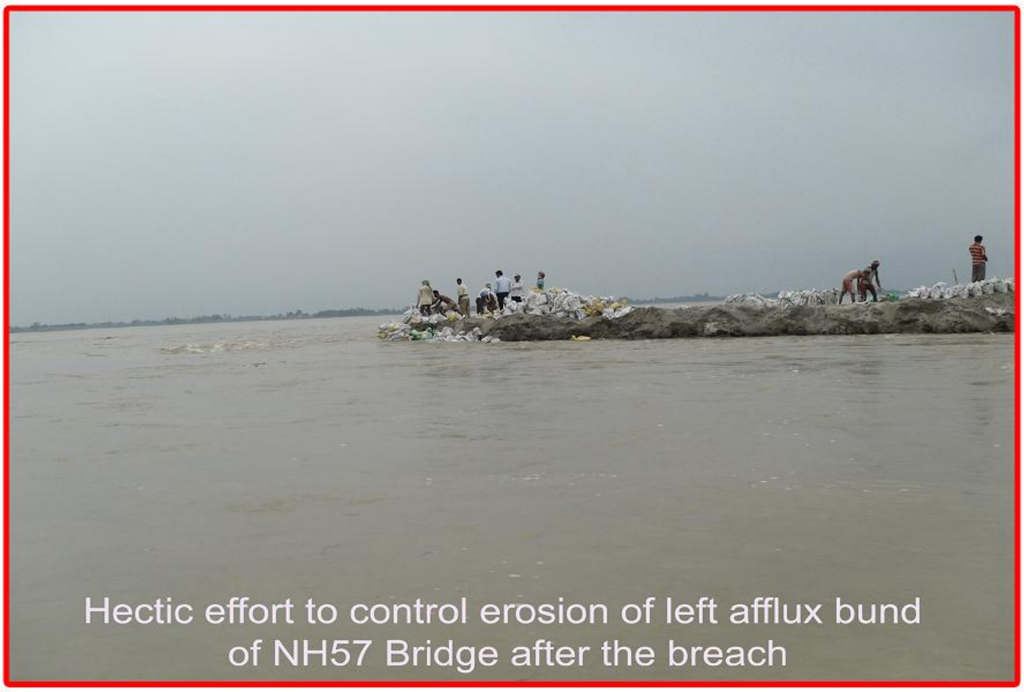


Photo 7.Breach in the Left Afflux cum Protection Embankment of the NH 57..

Photo 8. Shoal Formation Downstream of Railway Bridge Piers

Photo 9. Breach in the Left Guide Bund

Photo 10. Scouring of the NH-57 Piers after the first
Monsoon Floods in the River Kosi

P -23