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DESIGN & DEVELOPMENT OF PROTECTION SCHEME & SUPERVISORY CONTROL & DATA ACQUISITION SYSTEM (SCADA) OF 25 KV AC TRACTION SYSTEM FOR MUMBAI SUBURBAN SECTION ON INDIAN RAILWAYS (IR)

Margoob Hussain*, Sumit Bhatnagar R. K. Pal*** & R. K. Singh******

इस लेख में मुंबई उपनगरीय सेक्शन पर 25 केवी एसी कर्षण प्रणाली की विशेष आवश्यकताओं की पूर्ति हेतु सुरक्षा एवं पर्यवेक्षी नियंत्रण तथा डॉटा प्राप्ति (स्काडा) प्रणाली की डिजाइन, विकास एवं इसे चालू करने के बारे में बताया गया है। भारतीय रेलों पर सुरक्षा स्काडा प्रणाली के वर्तमान परिदृश्य एवं इसमें सुधार हेतु मुंबई के लिए नई प्रणाली विकसित कर ली गई है। इस लेख में आईईसी 60870-5-103 प्रोटोकाल पर आधारित रिपोर्ट टर्मिनल यूनिटों(आरटीयू) का न्यूमेरीकल रिले के साथ संयोजन के फायदों एवं सब- स्टेशन आटोमेशन क्षेत्र में की गई प्रगति के बारे में भी संक्षेप में प्रकाश डाला गया है।

मुख्य शब्द – स्काडा, सुरक्षा, आर.टी.यू, न्यूमेरीकल रिले, कर्षण, शिरोपारि उपस्कर, नियंत्रण, मॉनीटरिंग, प्रोटोकॉल, आईईसी

The paper is about the design, development & commissioning of protection & supervisory control and data acquisition (SCADA) system to meet special requirements of 25 kV ac traction system on Mumbai suburban section. The existing scenario of protection and SCADA systems on IR and improvements thereupon to develop the new system for Mumbai has been covered. The merits of integration of numerical relays with Remote Terminal Units (RTU) based on IEC 60870-5-103 protocol and other developments in the field of substation automation are also briefly discussed in the paper.

Keywords- **SCADA, protection, RTU, numerical relays, traction, railway, OHE, control, monitoring, protocol, IEC.**

1.0 INTRODUCTION

Electric traction in suburban areas of Mumbai started with 1500 Volts dc in year 1925; however during late nineties it was realised that dc traction system was grossly inadequate to cater for the ever increasing number of sub-urban train services and associated infrastructure. The decision was taken by the Ministry of Railways to convert existing 1500 V dc traction system to 25 kV ac.

Conversion of an existing 1500 V dc electric traction system to 25 kV ac had lots of constraints like minimum interruptions in train services, right of way i.e. space, clearances, fast developments in the field of protection and automation etc.

One of the important issues associated with the conversion work, was to economically design and develop a suitable protection scheme and SCADA system capable of controlling & monitoring large number of Circuit Breakers (CB)& Numerical relays provided at substation and switching posts in the Mumbai suburban area.

1.1 Brief Description of 1500V dc and 25 kV ac Systems

In old 1500 V dc system, the overhead equipment (OHE) power was being supplied at 1500 V from rectifier fed traction sub-stations (TSS) with normally no sectioning; i.e. the sub-stations were connected in parallel. In case of failure of one of the TSS, the supply was maintained from adjacent TSS. Total supply interruption for sub-urban trains Electrical Multiple Units (EMU) and the dc locomotive hauled main line trains was rare. Moreover, the motorman/ driver of the EMU's were not required to negotiate any neutral sections (switching off/on of rolling stock CB) thereby relieving them for better concentration on signals and driving.

In 25 kV ac system,power is drawn from two phases of the incoming EHV lines and stepped down to 25 kV. One of the secondary terminals of the transformer is earthed and other is connected to OHE to supply power.

Power is drawn from different phases at adjacent Traction Sub-stations (TSSs), cyclically, to balance the load on EHV transmission lines and hence the separation of phases is carried out on the OHE contact wire system by provision of "neutral sections", which do not draw power and provide mechanical continuity for passage of the pantograph of the motive power.

The drivers of trains are instructed to switch off the on-board 25 kV circuit breakers to prevent flashovers

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while the pantographs negotiate the neutral sections. Tripping of the feeder circuit breakers (CB) is associated with supply interruption over the entire feed zone.

1.2 Special Requirements of Protection, Control and Monitoring Systems

The single line diagram of the power supply arrangement at a TSS having details of protection relays for Mumbai suburban section and sectioning diagram for the conventional 25 kV ac traction system in use on IR are given in (Fig.1& 2) for comparing the two systems.The special requirements of traction power supply system for the Mumbai suburban section are as under.

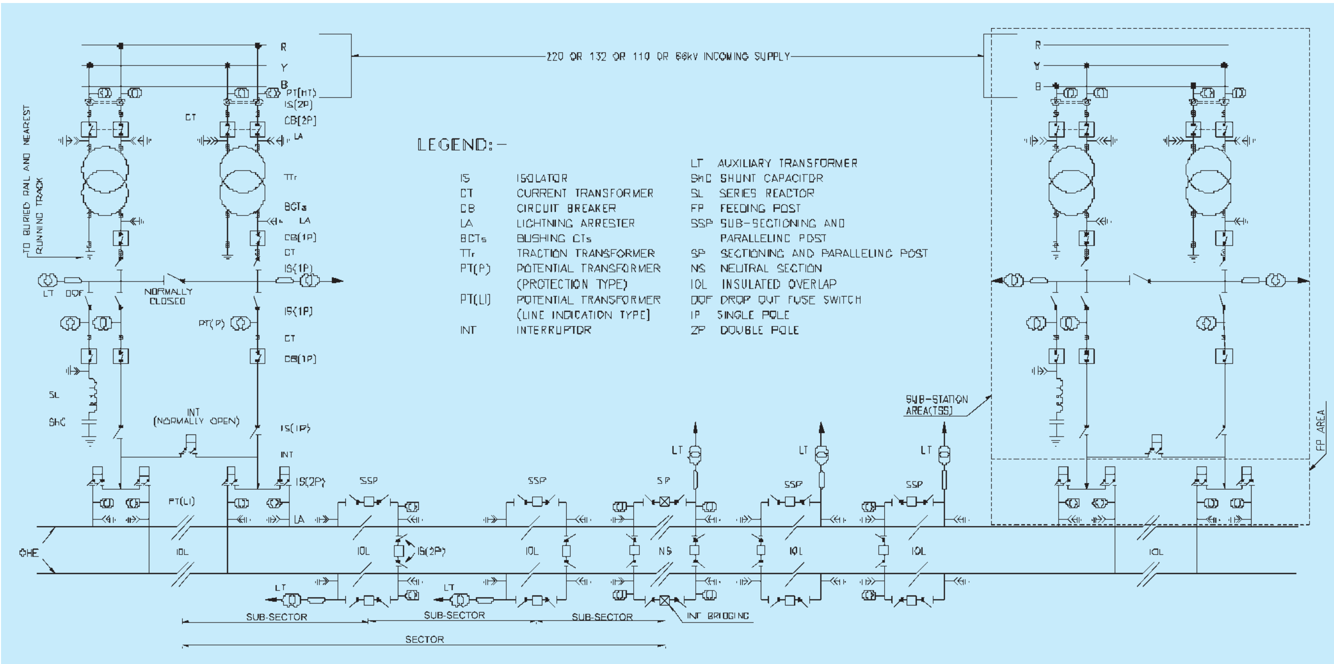

Fig. 1 : General scheme of supply for 25 kV 50 Hz. Single phase traction system

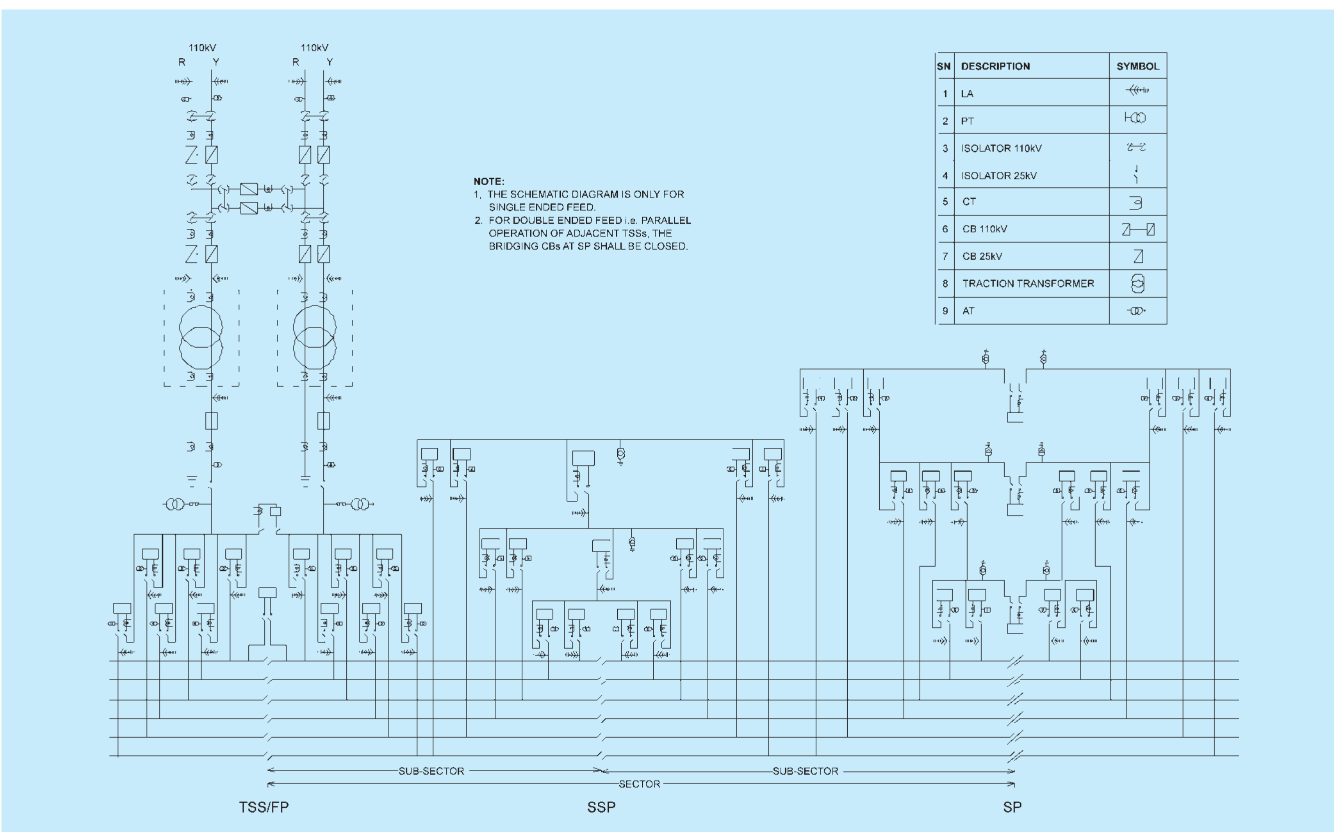

Fig. 2 : Schematic diagram for proposed 25 kV TSS, SSP & SP

1.2.1 Traction supply at different traction substations in Mumbai area is taken at 110 kV and up to three adjacent traction substations are to be fed at same phases from one supply authority and thus the TSSs drawing power from the same phases are planned to be operated in parallel on the 25 kV sides of the traction transformers. *In service, the "neutral sections" separating the sectors, are to be kept live, there-by providing operational convenience under paralleled feeds on both sides, during exigencies, however, the neutral sections shall be capable of being* ***activated*** *by operating the specific switches/ interrupters/ CBs.*

1.2.2 OHE system in Mumbai area consists of 4 to 8 Railway lines (tracks) with 25kV bus type arrangement atTraction Substations/Sectioning/ sub-sectioning & paralleling posts(TSS/ SP / SSP)as given in Fig. 3 below. TSSs are planned at short distances of 6.5 to 20 kms as against 50-60 kms due to higher power requirements. In addition, some of the sub-sectors (sections between any two switching stations) are very short, about 1 km.

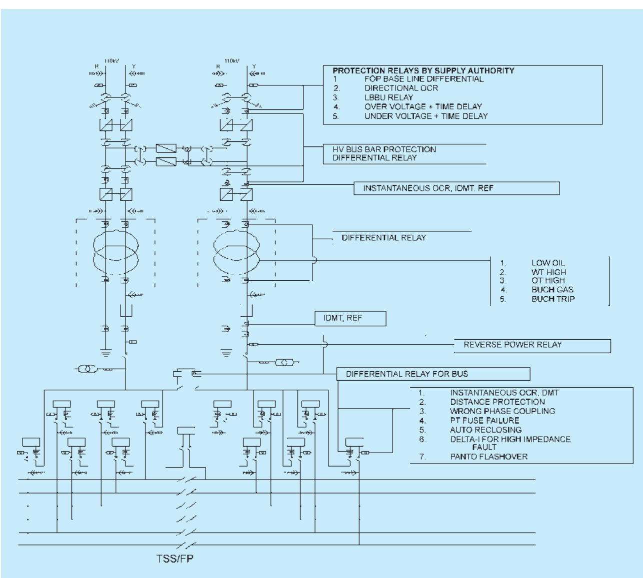

Fig. 3 : Protection scheme for proposed 25 kV TSS

1.2.3 All (SP/SSP)are provided with CB's in lieu of interrupters used in conventional 25kV ac traction system with protection relay sand associated control and relay panels so that the smallest possible section can be isolated & faults localized automatically, with minimum intervention by the operators.

1.2.3.1 The comparative requirements of telemetering & controls for Mumbai sub-urban section as compared to the conventional system are given below in Table-1

Table-1

Typical requirements of Equipment, input & outputs	Conventional Traction system on IR with double tracks TSS /SSP or SP	Mumbai Suburban Section with 8 tracks TSS /SSP or SP
No of Feeder CBs	2/nil	16/22
No. of Status / Alarms	96/28	600/600
Total No. of Controls	24/8	64/88
Parameters to be monitored	8/4	32/24

The hard wiring between RTU and panels for such large number of control points was not feasible due to space constraints (Fig 4).

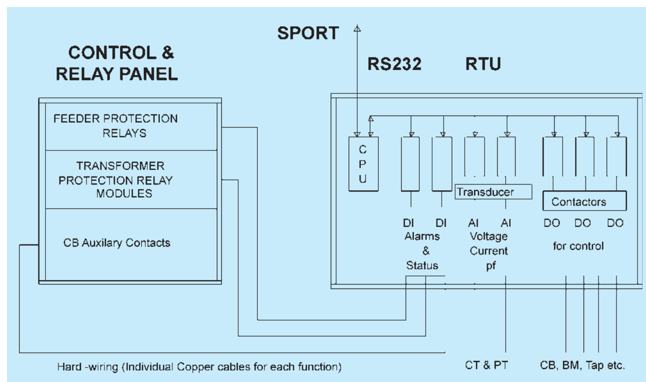

Fig. 4

1.2.3.2 The size of the RTU designed to cater for the above requirement of control points through hard wiring should have been very large to accommodate all the cards, relays/contactors and associated wiring circuits. Moreover, with long loops of CT secondary wiring, the chances of failures are also high.

1.2.4 OHE used in Mumbai suburban area is of varying configuration in terms of size of contact & catenary wires (e.g. Catenary/contact wire cross sections of 65/107, 65/150 & 242/193 Sq mm)and therefore its line parameters like values of R and X are expected to be different for different sections. More over some of the sections are equipped with auxiliary catenary as third wire. This creates difficulties in fault current assessments and relay settings thereon.

2.0 PROTECTION SCHEME ADOPTED FOR MUMBAI SUBURBAN SECTION

The main features of the protection scheme adopted are as under.

2.1 All the protection relays developed for this purpose were of Numerical type having IEC 60870-5-103 compatibility for communication with RTU's.

2.2 Incorporation of all modern features in protection relay module like, multiple protection functions per module, events/data storage, graphical LCD display, communication ports and compatibility to EMC & EMI norms as stipulated in latest IEC standards like IEC 60255-5, 60255-22-1, 60255-21-1, 60255-22-2,3,4,5,7 & IEC 61000-4-5 etc.

2.3 Optimum level of selectivity, to achieve isolation of minimum possible subsector in case of faults on OHE.

2.4 Adequate provision of backup protection systems to avoid any catastrophic failures. Additional protection features like "synchro check relay" to take care of paralleling of 25 kV supply of three TSS. The relay also has a feature to permit CB closing without synchronism check for feed extension.

2.5 Numbers of auxiliary relay functions have been built in a single protection relay module for minimizing the control panel wiring, number of auxiliary relays and burden on CTs, PTs & aux. 110V dc supply.

2.6 All protection relays have a self monitoring feature and in case of failureof the relay, alarm and tripping of CB can be realized as per requirement.

2.7 The different protection functions implemented in the new scheme are as under.

2.7.1 25 kV ac traction OHE feeder protection :

- Three Zone parallelogram characteristic distance protection relay with independent setting of R & X values for forward, reverse and each zone.
- Instantaneous and definite time over current, wrong phase coupling, PT fuse failure relays. Vectorial ΔI relays for high resistive faults protection as well as a backup protection to main feeder protection relays.
- Distance protection element have a automatic trip block feature by monitoring and analysing of second harmonic content of current to avoid unwanted tripping due to start-up of electric locomotives.
- Intelligent auto reclosure function has been inbuilt in the feeder protection module. The main feature of auto reclosure are:
  - ✓ Single or double shot user selectable reclosing with settable time delay.
  - ✓ Blocking of the reclosing of CB on high fault current.
  - ✓ Two types of auto reclosing logics to avoid CB reclosing on the both ends of the faulty subsector in case of permanent fault.
- SOTF (switch-on-to fault) function has been provided for high-speed tripping when energizing traction supply, on to a short-circuit fault.
- Memory polarization is used to discriminate correctly between faults in forward and reverse directions in the event of voltage input falling down to 0 volt.

2.7.2 Traction transformer protection

- Differential, Restricted Earth Fault (REF) and IDMT OCR protection along with three stage definite time OCR elements for both LV (25 kV) & HV (110 kV) sides.

2.7.3 LV and HV bus-bar differential protection

2.7.4 Protection scheme for 110 kV incoming transmission lines including reverse power flow relay at TSS to prevent reverse flow of power on transmission line through 25 kV Railway Feeder in case of parallel operation of TSS.

All the above listed protection relays are assembled on C&R panel toward the rear side, as shown in the Fig. 5.

Fig. 5 : Control and relay panel for TSS

3.0 SCADA SYSTEM ON IR

SCADA is one of the most critical system of electric traction network on IR as all the posts are unmanned. Since the inception of electric traction over IR in 1960's it started using SCADA based on electromechanical relays and mimic diagrams with switches. IR followed the developments in technology and gradually replaced its SCADA systems from electro mechanical to minicomputer based and to present PC based systems working on proprietary tailor made protocols like present SPORT protocol.

3.1 Conventional SCADA Communication System Working on IR

The schematic arrangement of conventional 25 kV ac traction SCADA system adopted over IR is depicted below in Fig. 6.

Slow speed V-23, FSK MODEMs, operating at 600/1200 bps are used on voice grade data channels over OFC and quad copper cable mediums in multi-drop, half duplex, unbalanced communication mode. The SCADA system is capable of collecting Digital and Analogue Inputs

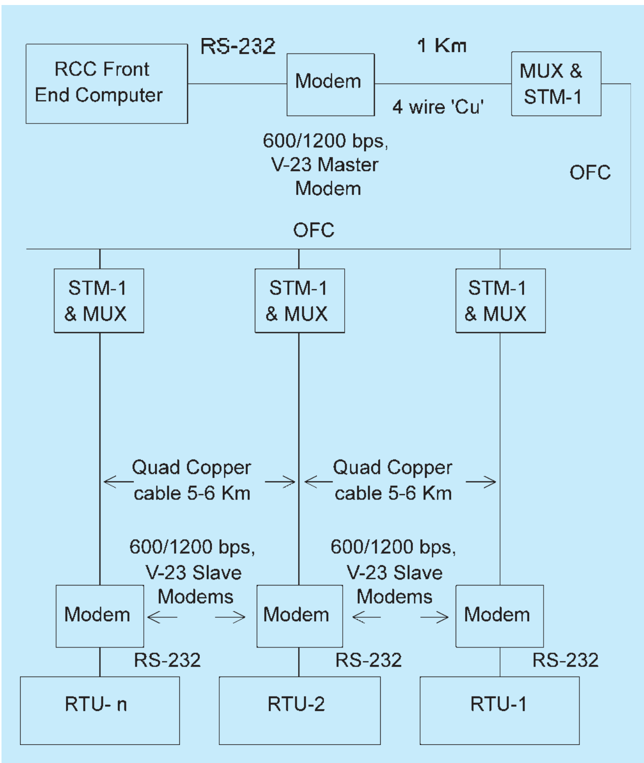

Fig. 6

(DI & AI) from field units and executing commands through Digital outputs (DO) for which hard wiring is done between RTU and control & Relay panels. The central location or Remote Control Centre (RCC) consists of server and workstation computers connected on a LAN and loaded with the SCADA application software for user interface and data interpretation, analysis & report generation.

Indian Railways has adopted SPORT (standard protocol for railway traction) communication protocol which is a customized and cut down version of IEC 60870-5-101 companion standard. This helps in efficient operations of the system even with very slow data transfer rates of 600/1200 bps.

4.0 OVERVIEW OF NEW SCADA SYSTEM - IEC 60870-5-103 BASED COMMUNICATION BETWEEN NUMERICAL RELAYS AND RTU

4.1. IEC 60870-5-103 is a companion standard of IEC 60870-5 series standards and applies to protection equipment with coded bit serial data transmission for exchanging information with control systems. It also defines interoperability between protection equipment and devices of a control system in a substation.

4.2. This standard does not necessarily apply to equipment that combines protection and control functions in the same device, sharing a single communication port, however, in case of Mumbai suburban section the numerical protection relays have been utilized for implementation of the control of devices i.e. circuit breakers by interfacing all such relays with RTU on RS 485 for communication thereby saving in terms of RTU hardware. The RS 485 may be single or multiple channel but in Mumbai area, multiple channels are used to reduce the load of communicable data in relays and to ensure redundancy as well (Fig. 8).

4.3. Either a fibre optic system or a copper-wire based transmission system may be used in this companion standard between the protection equipment and the control system.However copper wires are selected considering the cost and requirement levels. The RS-485 interface has been used for data communication between numerical relays and station controller units of the RTU.

4.4. The block diagram of the modified SCADA arrangement is given in Fig. 7a. Most of the information in the form of DI, DO and AI, like status of CB's, voltage, current, phase and command execution (i.e. ON/OFF of CB's) is accomplished through numerical relays connected via communication channels (Fig. 7b) thereby saving in terms of complicated hard wiring between RTU and control & relay panel. However, there is still some hard wiring because all the CB's, bus couplers etc.which are not controlled by any protection relays. The communication arrangement between RTU and RCC is same as depicted in the Fig. 5.

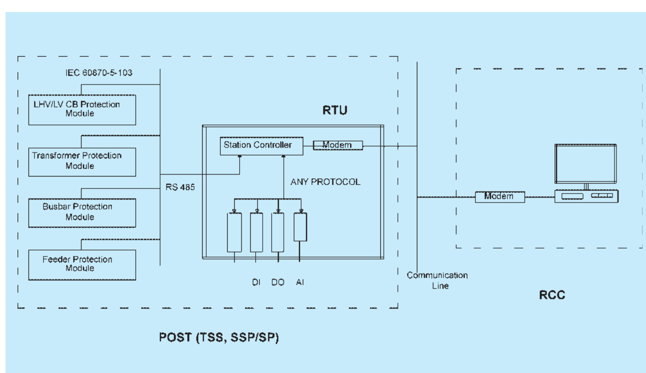

Fig. 7a

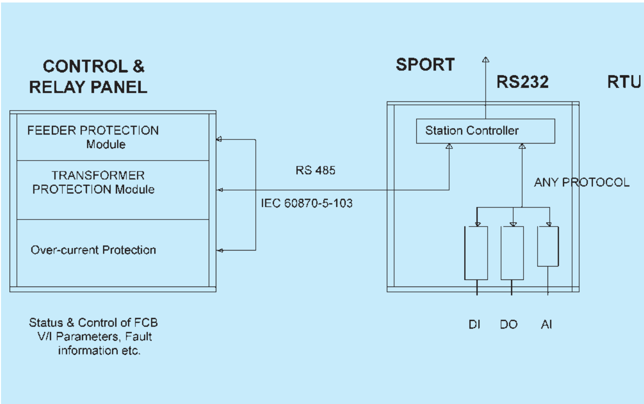

Fig. 7b

For RCC to RTU the data transfer speed is adjustable from 600 bps to 19200 bps. For communication with relays it is settable to either 9600 or 19200 bps as per IEC60870-5-103 standard.

4.5. The local control operation of devices from the control and relay panel has been retained through the hard wiring between panel, relays and switch gear devices same as in conventional system.

5.0 MERITS OF MODIFIED SCADA SYSTEM

5.1 Reduced hard wiring due to status, Control & acquisition of parameters accomplished from numerical protection relays.

5.2 Compact wall mounted Aluminum RTU could be done to save considerable space.

5.3 The smaller size and lesser components make system more reliable and require less maintenance. (Fig. 9 a & 9b)

5.4 The Station controller unit (SCU) of RTU is designed with multiple RS485 ports to reduce communication load on relays (Fig. 8). The SC is having a local HMI with LCD display & push button switches for local setting of parameters like address, communication speed, etc.

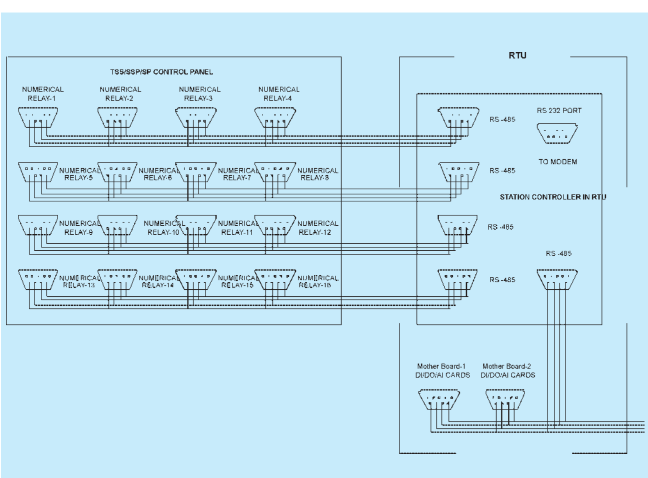

Fig. 8

Fig. 9(a)

Fig. 9 (b)

5.5 Improvements has also been done in the Control centre computers, LAN and SCADA software in terms of optimization of layout of computers in Remote Control Centre (RCC). All server, modems, switches, etc. are mounted in a compact rack. In addition complete automatic change-over of main server to stand-by in case of failure has been ensured. Synchronization to satellite time using GPS timer server has also been incorporated so as to ensure same time stamping at RCC and RTU's.

5.6 The design of controlling operations and status monitoring of devices (mainly CB's) through numerical relays has resulted in to large savings in terms of wiring, relays and contactors (for DO's).

5.7 There are no requirements of separate transducers for acquisition of analogue parameters like Voltage, current, power factor etc. as the information is provided by the relays.

5.8 The data which could not be read from the relays

For DI **For DO**

Table-2

Description	Description
25 kV Bridging Interrupters	25 kV Bus coupler
25 kV Bus coupler	HV Bus coupler
Transformer	25 kV Bridging Interrupters
Tap position	All HC CB
AC Fail	LV CB
DC Low	Tap Raise
DC Fail	Tap Lower
Any other annunciation circuit or 110 V dc failures.	

(as tabulated in table -2 above) was wired to separate Digital In, Digital Out & Analog In modules. These modules along-with associated contactors/relays were housed within the RTU.

5.9 The closing of circuit breakers through the feeder protection relays was achieved by using auto-reclosure function available in the feeder protection relays. A simple built in logic in the relay distinguishes the operation of breaker due to the operation of some protection element or by the controller at RCC.

6.0 FUTURE DEVELOPMENTS AND EMERGING TECHNOLOGIES FOR SUBSTATION AUTOMATION

There are rapid developments taking place in the field of protection, control, monitoring & integration of devices and substation automation technologies. The recent developments in this field are as under.

6.1 Development of Numerical Technology for Protection

Numerical protection relays are capable of implementing multiple protections, control and monitoring functions per hardware device, using a well crafted software platform. The devices are also capable of extensively using optical interface serial communication facilities.

With the use of these devices it is now possible to combine protection and control functions and it is now possible to transfer the useful data available in the form of sequence of events, disturbance reports, fault wave forms and even system parameters.

6.2 Standardization of Communication Protocols

The fast development of numerical technology necessitated standardisation of communication protocols and to some extent, of the substation bays, layouts and protection functions. The serial communication was standardised by IEC in its 60870-5 series of standards. The IEC 60870-5-101/104 companion standards defined the communication between substation and remote control centre, while IEC 60870-5-103 for communication with protection equipment. The standard protocols like DNP3, Modbus etc. are also being utilized extensively by electrical utilities.

6.3 Complete Substation Automation & Integration of all IED's

The latest development has been the evolution of IEC 61850 standard,which comprehensively covers all communication issues within the substation, assures interoperability between the functions existing inside the substation and is virtually considered to be future proof.It uses 100 Mbps Ethernet substation LAN & switches, object oriented data model having logical nodes under client server architecture for non time critical data transmission and Generic Object Oriented Substation Event (GOOSE) for exchange of time critical data between same bay or horizontal communication.

The IEC 61850 was not considered for the Mumbai project because there were limited suppliers & developers of Numerical Relays, IED's and other IEC 61850 compliant field devices. The cost of the devices complying with the above standard is high and the complexity, voltage levels, number of bays and configurations of the Railways TSS and switching posts as compared to the HV/EHV Grid Substations was much less therefore it was not selected for Mumbai traction system.

In addition to above, other aspects like complexities involved in implementation of the IEC 61850, limited technical expertise available at grass root level and availability of brief past experience of such systems in India were also the deterring factors.However latest substation automation standards like IEC 61850 may be considered for major Railway Electrification projects of Indian Railways in future.

7.0 SUMMARY

Indian Railways has taken a leap ahead by adopting a new technology for 25 kV ac traction protection and SCADA application at Mumbai suburban section to meet the special requirements of the area like 6-8 lines, space constraints, parallel operation of 2 to 3 TSS, small subsectors etc. New designs of numerical relays and control and relay panels were developed and provided. The results have been encouraging and the system comprising of 7 posts and nearly 30 km section between Borivali and Virar stations have already been commissioned and is working satisfactorily as per the new protection scheme and SCADA system.

REFERENCES

1 Trends in Protection & Substation Automation Systems: Integration Standardization, Information Technology by De Mesmaekar Ivan, Key note address, 4th International Conference on Power System Protection & Automation 21-22 Nov. 2007, CBIP, New Delhi.

2 IEC 60870-5-103 Transmission protocols – companion standard for the informative interface of protection equipment.

3 IEC 60870-5-101 Telecontrol equipment and systems – Part 5-101: Transmission protocols – Companion standard for basic telecontrol tasks.

4 M/s ASHIDA Electronics Pvt. Ltd., Mumbai. Manuals for Traction protection relays.

5 Research Designs & Standards Organization (RDSO), Indian Railways Specification No. TI/SPC/PSI/PROTCT/4050(10/2005) and TI/SPC/RCC/SCADA/1080(9/08) with Amendment No.1.

6 Practical Modern SCADA Protocols By Gordon Clarke, Deon Reynders & Edwin Wright, Imprint of Elsevier, 2004.

7 Understanding microprocessor based technology applied to relaying, Power system relaying committee, report of working group I16 of the relaying practices subcommittee, Feb 2004.

8 Design of IEC 61850 based substation automation systems according to customer requirements K.P. BRAND, C. BRUNNER, W. WIMMER ABB Switzerland Ltd, Baden and Zürich, CIGRE, B5-103, 2004.

FATIGUE LIFE ASSESSMENT OF STEEL GIRDER BRIDGES ON INDIAN RAILWAYS – A STUDY BASED ON NEW FATIGUE PROVISIONS

R.K. Goel*

भारतीय रेल द्वारा, कुछ वर्ष पूर्व, वर्तमान रेलमार्गों पर अधिक धुराभार सफलतापूर्वक चलाया गया है। इन रेल मार्गों पर यद्युपि रेलपथ का नवीनीकरण एंव गिट्टी की कमी को पूरा किया जाता रहा है, किन्तु पुलों पर किसी प्रकार की मरम्मत अथवा सशक्तिकरण का कार्य नहीं किया गया है। अतः बढ़े हुए धुरा भार के अधीन कार्यरत, इन पुराने पुलों के गर्डरों की सक्षमता का आकलन करना, सदैव महत्वपूर्ण रहा है। सैद्धान्तिक रुप से यह माना जाता है कि, अधिक धुरा भार वहन करने से, इन गर्डरों की रेसिड्वल फैटिक लाईफ (Residual Fatigue life) में कमी आएगी, किन्तु इस प्रकार की कमी का गणितीय आकलन करने के लिए, अभी तक भारतीय रेल के पास कोई मानक आधार नही था। अनुसंधान, अभिकल्प व मानक संगठन (RDSO), लखनऊ के द्वारा, अभी हाल ही में, अन्तराष्ट्रीय मानकों (Euro Codes) के अनुरुप नये फैटिग प्रावधान विकसित किये गये हैं, जिनके माध्यम से न केवल अधिक धुरा भार, बल्कि अधिक गति के भी, रेसिड्वल फैटिग लाईफ पर पड़ने वाले प्रभावों का, गणितीय आकलन करना सम्भव हो गया है। इस तकनीकी लेख में रेसिड्वल फैटिग लाईफ आकलन की संक्षिप्त कार्यविधि तथा मानक स्टील गर्डरों पर किये गये अध्ययनों के परिणाम प्रस्तुत किये गये हैं।

Indian Railways has recently permitted increased axle load on existing routes. Although the track structure on these routes have undergone track renewal and ballasting, the bridges have not been provided with any kind of input or strengthening. Moreover, strengthening of existing bridges with running traffic is not possible, without imposing speed restrictions for a very long duration. Therefore, the performance of existing bridge girders under heavy axle loads has always been an issue. Though, it is accepted that the running of heavy axle load will affect the residual fatigue life of the existing steel girders, there has been no standard provisions on Indian Railways to mathematically evaluate such effects. RDSO has recently developed draft fatigue provisions, in line with latest international provisions (Euro Codes) which make it possible to evaluate not only the effect of running heavy axle loads, on the residual fatigue life but also the effect of the speed. This paper presents the brief methodology of fatigue life evaluation and the results of the study made on standard steel girders.

1.0 INTRODUCTION

1.1 Indian Railway has recently permitted over utilization of carrying capacity of it's wagons for generating extra revenue. This has increased axle loads of wagons and the magnitude of trailing load (TLD) has been increased from 8.25 t per meter to 9.33 t per meter.

1.2 The issue of fatigue life reduction has been raised quite often and it is accepted that running of heavy axle load will result in early replacement of girder bridges. It is to be noted that most of the railway bridges have been designed for Indian Railways standard loadings such as BGML, RBG & MBG which are having varying equivalent uniformly distributed loads. The net effect of increased trailing load is to increase the maximum stress range to which the members are subjected and therefore greater fatigue damage is expected. Till now there were no rational provisions in IRS code to mathematically evaluate such effects of heavy axle loads.

1.3 The issue of revision of fatigue provisions in IRS steel bridge code had been under discussion for quite some time. Detailed studies have been carried out by RDSO on the issue and draft provisions have been issued for adoption. These provisions have also been discussed in 78th Bridge Standard. The workability and suitability of these provisions has been ascertained by applying the provisions on existing standard designs of RDSO. On the basis of results of the exhaustive study carried out, new provisions have been formulated and draft correction slip no. 18 to IRS Steel Bridge Code has been sent to Railway Board.

1.4 A study on assessment of fatigue life of existing standard steel girders has been done by RDSO based on the simplified approach of the revised fatigue provisions. This paper presents the approach used and the results of the study.

2.0 SIMPLIFIED APPROACH OF REVISED IRS PROVISIONS

2.1 Fatigue Stress Spectra

2.1.1 For the simplified fatigue loading the following procedure is adopted to determine the design stress spectrum.

2.1.2 The recommended equivalents for train loads shall be adopted in accordance with existing provisions of IRS Bridge Rules, including the dynamic impact factor F, which is calculated as (1.0 + CDA),

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where CDA is the coefficient of Dynamic Augment as specified in IRS Bridge Rules.

2.1.3 The maximum stress $\sigma_{P,max}$ and the minimum stress $\sigma_{P,min}$ should be determined for a detail or structural connection. The $\sigma_{P,max}$ is for Dead Load + Full Live Load with dynamic impact factor 'ϕ' whereas the $\sigma_{P,min}$ is for dead load effects only.

2.1.4 The reference stress range $\Delta\sigma_P$ for determining the damage due to the stress spectrum should be obtained from:

$$\phi * \Delta\sigma_P = |\sigma_{P,\max} - \sigma_{P,\min}|$$

2.1.5 The damage effects of the stress range spectrum may be represented by the damage equivalent stress range related to 2 million cycles as

$$\Delta\sigma_{E,2} = \lambda * \Phi * \Delta\sigma_P$$

Where,

λ is the damage equivalence factor, and

Φ is the dynamic impact factor (1.0 + CDA),

CDA is the coefficient of Dynamic Augment as specified in Bridge Rules

2.2 Fatigue Assessment

The fatigue assessment shall be carried out by ensuring the satisfaction of the following criteria:

$$\gamma_{Ff} * \Delta\sigma_{E,2} \leq \Delta\sigma_C / \gamma_{Mf}$$

Where,

$\Delta\sigma_C$ is the reference value of the fatigue strength at N_C = 2 million cycles

γ_{Mf} is the partial safety factor for material

γ_{Ff} is the partial safety factor for loads

2.3 Damage Equivalence Factors

2.3.1 The damage equivalent factor for railway bridges should be determined from:

$\lambda = \lambda_1 * \lambda_2 * \lambda_3 * \lambda_4$

subject to the condition that $\lambda \leq \lambda_{max}$

where

λ_1 is a factor that takes into account the damaging effect of traffic and depends on the base length of the longest loop of the influence line diagram.

λ_2 is a factor that takes into account the annual traffic volume in million tonnes.

λ_3 is a factor that takes into account the design life of the bridge in years.

λ_4 is a factor to be taken into account when the bridge structure is loaded on more than one track.

λ_{max} is the maximum λ value taking into account the fatigue limit and is equal to 1.4.

2.3.2 The loaded length for the determination of the appropriate λ_1 should be taken as follows:

- for moments:
  - For a simply supported span, the span length, L
  - For cross girders supporting rail bearers (or stiffeners), the sum of the spans of the rail bearers (or stiffeners) carried by the cross girder.
- for shear for a simply supported span
  - For the support section, the span length
  - For the mid-span section, 0.4 * the span under consideration.
- In other cases.
  - the same as for moments.
- for truss members.
  - base length of the largest loop of Influence line diagram.

2.3.3 The value of λ_2 , in terms of the annual volume of traffic may be obtained from the following expression:

$$\lambda_2 = 0.5193 * T_a^{\ 0.2036}$$

Where T_a is the annual volume of traffic expressed in million tonnes.

2.3.4 Unless otherwise specified by the competent authority the value of λ_3 will be taken as 1.04 for a design life of 120 years. For other values of design life the corresponding value may be calculated from the following expression where L_D is the design life in years

$$\lambda_3 = 0.3899 * L_D^{\ 0.2048}$$

2.3.5 The value of λ_4, assuming 15% of the total traffic on both tracks crosses whilst on the bridge, unless specified otherwise by the competent authority, shall be obtained from

λ_4 = 0.7926* a² - 0.7280 *a + 0.9371

where

a = $\Delta\sigma_1 / \Delta\sigma_{1+2}$

$\Delta\sigma_1$ = Stress range at the section being checked due to train on one track.

$\Delta\sigma_{1+2}$ = Stress range at the same section due to train load on two tracks.

The values of λ_4 may be calculated for other proportions of crossing traffic from

$$\lambda_4 = \sqrt[5]{n + (1-n)\left[a^5 + (1-a)^5\right]}$$

where

n is the proportion of traffic that crosses whilst on the bridge.

2.3.6 The value of λ should not exceed λ_{max} which is specified as 1.4.

3.0 DETERMINATION OF λ_1 PARAMETERS

3.1 The fatigue life assessment has been done for MBG loading and 25t loading as given in IRS Bridge Rule. The fatigue load model for these loading have been developed and λ_1 parameters worked out in association with IIT/Roorkee using Artificial Neural Network Technique. The data of European trains as given in Euro Codes has been used for the purpose.

3.2 The value of λ_1 is to be obtained from tables 1(a) & 2(a) for MBG loading and 25t loading - 2008 respectively as a function of the loaded length. These values have been worked out as per the train types included in the respective standard traffic load models for MBG loading and 25t loading. The types of trains and their frequencies for a specified GMT are given in Table 1(b) and 2(b) for the two loadings respectively. The loaded length shall depend upon the influence line diagram of the structural detail/connection under consideration. The traffic load models are particularly important when detailed fatigue analysis is required.

4.0 ASSESSMENT METHOD AND ASSUMPTIONS

- Maximum stress range taken as the difference of dead load stress and the maximum stress likely to come in the member with DL, Impact load and live load. The maximum bending stresses due to equivalent uniformly distributed load for IRS loadings given in Bridge Rules have been worked out and the maximum stress range calculated.
- In the analysis of plate girder only the bending stresses due to maximum bending moment have been taken into consideration to find out the maximum stress range and the design fatigue life of spans has been assessed.
- Occasional loads have not been considered.
- The members having stresses in compression throughout the passing of dynamic load over the bridge are assumed to have infinite design life.
- For plate girders, the loaded length for considering λ_1 has been taken, as effective span length.
- GMT factor is taken as per proposed fatigue criteria in 78th BSC.
- Fatigue categories are chosen as per the Table – 3 which is based on the tables given in draft provisions, discussed in 78th BSC and the engineering judgment applied. The analyzed fatigue life may vary on this account.

5.0 FATIGUE LIFE ASSESSED

5.1 Based on above assumptions, the design calculations for assessment of fatigue life of plate girder bridges are given in Table - 4 for MBG loading and in Table - 5 for 25t loading.

5.2 It is to be noted that the annual GMT for a particular route may not be comprised of the trains causing maximum stress range. Situation may vary route wise and partial GMT may be due to trains causing much lower stress range. In such cases a more detailed fatigue assessment would be required taking into consideration the representative load model of actual set of trains running on the route.

5.3 It is further to be observed that due to change of loading, the λ_1 values and the maximum design stress-ranges have increased marginally. However, the effect on design

Table- 1(a) : λ_1 for MBG loading

Span (m)	Train-1	Train-2	Train-3	Train-4	Train-5	Train-6	Train-7	Train-8	Train-9	Train-10
0.50	1.1996	1.3377	1.3342	1.1477	1.3353	**1.5986**	1.5681	1.3336	1.2672	1.2849
1.00	1.1775	1.3266	1.3111	1.1360	1.3320	**1.5893**	1.5698	1.3318	1.2590	1.2748
1.50	1.1615	1.3106	1.2820	1.1218	1.3314	**1.5756**	1.5730	1.3293	1.2552	1.2634
2.00	1.1470	1.2903	1.2674	1.1039	1.3318	1.5650	**1.5769**	1.3267	1.2537	1.2473
2.50	1.1288	1.2651	1.2559	1.0820	1.3317	1.5617	**1.5809**	1.3252	1.2523	1.2290
3.00	1.1050	1.2339	1.2460	1.0502	1.3303	1.5618	**1.5839**	1.3254	1.2502	1.2174
3.50	1.0741	1.1963	1.2367	1.0063	1.3281	1.5614	**1.5856**	1.3270	1.2474	1.2121
4.00	1.0386	1.1537	1.2270	0.9639	1.3254	1.5620	**1.5859**	1.3291	1.2442	1.2077
4.50	0.9986	1.1100	1.2157	0.9294	1.3222	1.5627	**1.5856**	1.3312	1.2406	1.2024

Span (m)	Train-1	Train-2	Train-3	Train-4	Train-5	Train-6	Train-7	Train-8	Train-9	Train-10
5.00	0.9503	1.0694	1.2014	0.8953	1.3188	1.5636	**1.5860**	1.3327	1.2367	1.1961
6.00	0.8699	0.9994	1.1606	0.8247	1.3112	1.5663	**1.5876**	1.3362	1.2286	1.1843
7.00	0.8451	0.9574	1.1341	0.7469	1.3031	1.5590	**1.5823**	1.3184	1.2216	1.1666
8.00	0.8300	0.9389	1.1075	0.6797	1.2957	1.5299	**1.5736**	1.3142	1.2173	1.1446
9.00	0.8175	0.9282	1.0628	0.6437	1.2884	1.4952	**1.5621**	1.3117	1.2146	1.1102
10.00	0.8676	0.9588	1.0191	0.5600	1.1653	1.2961	**1.3417**	1.1167	1.1238	1.0127
12.50	0.8462	0.9549	0.9896	0.5421	1.1416	1.2469	**1.2912**	1.1127	1.1205	0.9585
15.00	0.8263	0.9376	0.9505	0.5439	1.1252	1.1911	**1.2392**	1.1087	1.1114	0.9302
17.50	0.8162	0.9168	0.9056	0.5563	1.0956	1.1457	**1.1787**	1.1047	1.0814	0.9170
20.00	0.8558	0.9087	0.8477	0.5905	1.1604	**1.1808**	1.1717	0.9881	1.1445	0.8985
25.00	0.7783	0.7977	0.7779	0.5846	1.1146	1.0770	**1.1297**	0.9740	1.0955	0.8607
30.00	0.7553	0.7700	0.7163	0.5551	**1.0888**	1.0312	1.0675	0.9646	1.0616	0.8149
35.00	0.7307	0.7225	0.6843	0.5103	**1.0649**	0.9918	1.0005	0.9729	1.0455	0.7745
40.00	0.7162	0.7040	0.6632	0.5391	**1.0403**	0.9096	0.9651	0.9787	1.0377	0.7437
45.00	0.6884	0.6742	0.6497	0.5367	**1.0243**	0.8560	0.9229	0.9781	0.9996	0.7234
50.00	0.6494	0.6555	0.6411	0.5154	**1.0048**	0.7993	0.8834	0.9739	0.9546	0.7101
60.00	0.5494	0.6384	0.6346	0.4315	**0.9696**	0.7129	0.8208	0.9619	0.8765	0.6847
70.00	0.5282	0.5849	0.6367	0.4211	0.8868	0.6692	0.7579	**0.9474**	0.8288	0.6658
80.00	0.5020	0.5398	0.6156	0.4219	0.8213	0.6506	0.7126	**0.9286**	0.8037	0.6516
90.00	0.4739	0.5128	0.5324	0.4127	0.7781	0.6456	0.6807	**0.9048**	0.7785	0.6367
100.00	0.4521	0.4893	0.5039	0.4047	0.7205	0.6416	0.6593	**0.8836**	0.6921	0.6272

Table- 1(b) : Traffic load models for MBG standard

Type of Train	Train No.	Train Composition	Weight per Train (t)	GMT per Train	Class of Traffic							
					Heavy Freight Traffic (100 GMT)		Mixed Traffic Lines with Heavy Traffic (70 GMT)		Suburban Traffic (60 GMT)		Mixed Traffic Lines with Light Traffic (40 GMT)	
					No. of Trains	GMT	No. of Trains	GMT	No. of Trains	GMT	No. of Trains	GMT
Passenger Trains	1	1+152	900	0.33	3	1.0	6	2.0	-	-	5	1.7
	2	2+22	1400	0.51	2	1.0	10	5.1	5	2.6	5	2.6
	3	2+2AC+24NonAC	1700	0.62	-	-	14	8.7	5	3.1	-	-
	4	EMU 12	700	0.26	-	-	-	-	200	52.0	-	-
Freight Trains loaded	5	1+75-4 Wheeler	3200	1.17	2	2.3	2	2.3	-	-	2	2.3
	6	2+40 BOX	3600	1.31	2	2.6	-	-	-	-	5	6.5
	7	2+55 BOXN	5100	1.86	10	18.6	4	7.4	-	-	10	18.6
	8	2(2+55 BOXN)	10300	3.76	20	75.2	12	45.1	-	-	2	7.5
Freight Trains empty	9	1+75-4 Wheeler	1100	0.40	-	-	-	-	-	-	2	0.8
	10	2+40 BOX	1300	0.47	-	-	-	-	-	-	2	0.9
Total						100.7		70.6		57.7		40.9

Table - 2(a) : λ_1 for 25 t loading

Span (m)	Train-1	Train-2	Train-3	Train-4	Train-5	Train-6	Train-7	Train-8	Train-9	Train-10	Train-11
0.50	1.2278	1.3574	1.5043	0.6903	1.4369	**1.6074**	1.3131	1.3236	1.3923	1.3121	1.2930
1.00	1.2042	1.3435	1.4886	0.6762	1.4284	**1.6003**	1.3160	1.3199	1.3883	1.3031	1.2889
1.50	1.1862	1.3283	1.4708	0.6625	1.4198	**1.5970**	1.3230	1.3156	1.3842	1.2998	1.2847
2.00	1.1707	1.3124	1.4509	0.6500	1.4114	**1.5948**	1.3297	1.3106	1.3804	1.2988	1.2801
2.50	1.1556	1.2951	1.4279	0.6383	1.4038	**1.5928**	1.3301	1.3049	1.3766	1.2982	1.2746
3.00	1.1410	1.2750	1.4001	0.6246	1.3971	**1.5910**	1.3218	1.2987	1.3712	1.2965	1.2681
3.50	1.1227	1.2503	1.3660	0.6073	1.3915	**1.5895**	1.3132	1.2922	1.3639	1.2932	1.2605
4.00	1.0910	1.2195	1.3274	0.5859	1.3865	**1.5889**	1.3132	1.2858	1.3617	1.2884	1.2515
4.50	1.0393	1.1835	1.2924	0.5631	1.3811	**1.5906**	1.3154	1.2802	1.3644	1.2829	1.2412
5.00	0.9765	1.1453	1.2656	0.5443	1.3724	**1.5930**	1.3182	1.2761	1.3674	1.2778	1.2296
6.00	0.8968	1.0749	1.2128	0.5239	1.3494	**1.5961**	1.3216	1.2728	1.3610	1.2736	1.2039
7.00	0.8796	1.0144	1.1493	0.5148	1.3371	**1.5981**	1.3215	1.2705	1.3307	1.2669	1.1742
8.00	0.8692	0.9717	1.0911	0.5069	1.3073	**1.5971**	1.3204	1.2680	1.2870	1.2586	1.1416
9.00	0.8626	0.9473	1.0537	0.4997	1.2605	**1.5930**	1.3186	1.2665	1.2515	1.2494	1.1163
10.00	0.9047	0.9682	1.0109	0.5456	1.0825	**1.3503**	1.1921	1.1708	1.0788	1.1092	0.9719
12.50	0.8925	0.9620	0.9572	0.5315	1.0711	**1.3002**	1.2022	1.1743	1.0851	1.0845	0.9463
15.00	0.8806	0.9198	0.9468	0.5220	1.0534	**1.2432**	1.1971	1.1877	1.0566	1.0317	0.9249
17.50	0.8274	0.8937	0.9165	0.5157	1.0076	**1.2011**	1.1833	1.1917	0.9964	0.9946	0.8925
20.00	0.8262	0.8995	0.8962	0.5253	0.9897	**1.2124**	1.1808	1.1590	0.9845	0.9422	0.8102
25.00	0.8065	0.8712	0.8906	0.5104	0.9690	1.1650	**1.1806**	1.1591	0.9911	0.9302	0.7540
30.00	0.7899	0.7774	0.8768	0.5091	0.9401	1.1004	**1.1797**	1.1588	0.9804	0.9241	0.7012
35.00	0.7706	0.7643	0.8657	0.5055	0.9058	1.0415	**1.1781**	1.1577	0.9472	0.8938	0.6568
40.00	0.7554	0.7290	0.7835	0.5019	0.8702	0.9786	**1.1759**	1.1546	0.9056	0.8550	0.6224
45.00	0.7270	0.7037	0.7470	0.4955	0.8395	0.9766	**1.1733**	1.1497	0.8677	0.8156	0.6101
50.00	0.6863	0.6814	0.7148	0.4877	0.8171	0.9733	**1.1706**	1.1444	0.8364	0.7789	0.6778
60.00	0.5832	0.6552	0.6815	0.4813	0.8197	0.9241	**1.1637**	1.1318	0.7877	0.7392	0.6610
70.00	0.5486	0.6046	0.6601	0.4823	0.8529	0.8500	**1.1552**	1.1164	0.8249	0.7086	0.6352
80.00	0.5090	0.5570	0.6458	0.4861	0.7976	0.7703	**1.1484**	1.0992	0.7609	0.6729	0.6087
90.00	0.4738	0.5367	0.5849	0.4999	0.7276	0.7245	**1.1400**	1.0743	0.6793	0.6579	0.5898

Table - 2(b) : Traffic load models for MBG s tandard

Type of Train	Train No.	Train Composition	Weight per Train(t)	GMT per Train	Class of Traffic: Heavy Freight Traffic (100 GMT) No. of Trains	GMT	Mixed Traffic Lines with Heavy Traffic (70 GMT) No. of Trains	GMT	Suburban Traffic (60 GMT) No. of Trains	GMT	Mixed Traffic Lines with Light Traffic (40 GMT) No. of Trains	GMT
Passenger	1	1+15ICF COACH NON AC	900	0.33	3	1.0	6	2.0	-	-	5	1.7
	2	2+22 ICF COACH NON AC	1400	0.51	2	1.0	10	5.1	7	3.57	5	2.6
	3	2+26 COACH AC	1700	0.62	-	-	14	8.7	7	4.34	-	-
	4	EMU12	700	0.26	-	-	-	-	200	52.0	-	-
Freight	5	2(22.5T)+40 BOXN	4270	1.56	2	3.1	-	-	-	-	4	6.24
	6	2(25T)+55 BOXN	5800	2.12	8	16.96	4	8.48	-	-	9	19.08
	7	2E(2+55 BOXN)	11540	4.21	10	42.1	6	25.21	-	-	1	4.21
	8	2D(2+55 BOXN)	11600	4.23	8	33.84	5	21.15	-	-	1	4.23
	9	Bo-BO +40 BOXN	4200	1.53	2	3.06						
Freight empty	10	2(25T)+55BOXN	1686	0.61	-	-	-	-	-	-	1	0.61
	11	2(22.5T)+40 BOXN	1278	0.47	-	-	-	-	-	-	2	0.9
Total					35	101.06	45	70.64	214	59.91	28	39.57

Table- 3 : Fatigue categories adopted for member detail/connections

S.No.	Member detail or connection to be assessed	Fatigue category: Category	Fatigue category: Reference	Remark
1	Stringer, X-girder & Plate girders (welded type)	100	Details 5 & 6 of Table 9.2	Bending stresses at mid of span
	Stringer, X-girder & Plate girders (rivetted type)	80	Detail 8 of Table 9.1	
2	Fillet weld of web-flange connection		Detail 8 of Table 9.5	Shear stress at
	of stringer/x-girder	80		throat area of weld.
3	Gusset connections	80	Detail 8 of Table 9.1	Axial stresses on net area.
4	Stringer and x-girder connection	100	Detail 11 of Table 9.1	Shear stress on shank area of rivet/bolt

fatigue life has been considerable on higher spans as compared to smaller spans.

6.0 EFFECT OF SPEED ON THE ASSESSED DESIGN FATIGUE LIFE

6.1 It is evident from the perusal of Table 4 & 5 that the assessed fatigue life is quite low for high GMT routes and the spans designed for 2 million cycles as per old fatigue provisions based on stress ratio concept. This is apparently due to the fact that the stress ranges considered in analysis are based on full CDA (Coefficient of Dynamic Augment) which is applicable for a speed 125 kmph for goods trains. Practically, goods trains do not run with a speed more than 100 kmph. Therefore, the design fatigue life has been re-assessed with reduced stress ranges corresponding to a sectional speed of 100 kmph by proportionately reducing the maximum design stress range. The results for re-assessed design life for MBG loading and 25t loading are shown in table 6 & 7 respectively.

Table - 4 : Assessed fatigue life of standard plate girder bridges (MBG loading)

Std. Span	RDSO Drg. No.	Stress Range σ_{Rmax} (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
					5	10	20	30	40	50
					0.721	0.830	0.956	1.038	1.101	1.152
12.2m MBG	B-16009 (4 million)	118.33	13.1	1.28	64.802	32.533	16.333	10.914	8.200	6.568
12.2m MBG	B-16012 (10 million)	95.75	13.1	1.28	182.219	91.480	45.926	30.690	23.057	18.469
18.3m MBG	B-16010 (4 million)	109.35	19.4	1.18	141.727	71.152	35.721	23.870	17.933	14.365
18.3m MBG	B-16013 (10 million)	84.22	19.4	1.18	507.201	254.633	127.834	85.426	64.177	51.409
24.4m MBG	B-16011 (4 million)	93.02	25.6	1.125	394.140	197.872	99.339	66.383	49.871	39.949
24.4m MBG	B-16005 (10 million)	84.15	25.6	1.125	642.927	322.772	162.043	108.285	81.351	65.166
12.2m BGML	B-11003 (2million)	112.88	13.1	1.28	27.440	13.776	6.916	4.622	3.472	2.781
18.3m BGML	B-11004 (2 million)	111.86	19.4	1.18	42.671	21.422	10.755	7.187	5.399	4.325
24.4m BGML	B-11005 (2 million)	107.2	25.6	1.125	66.311	33.290	16.713	11.168	8.390	6.721

Table - 5 : Assessed fatigue life of standard plate girder bridges (25 t loading)

Std. Span	RDSO Drg. No.	Stress Range σ_{Rmax} (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
					5	10	20	30	40	50
					0.721	0.830	0.956	1.038	1.101	1.152
12.2m MBG	B-16009 (4 million)	118.31	13.1	1.29	62.437	31.346	15.737	10.516	7.900	6.329
12.2m MBG	B-16012 (10 million)	95.73	13.1	1.29	175.603	88.159	44.259	29.576	22.220	17.799
18.3m MBG	B-16010 (4 million)	114.75	19.4	1.21	101.106	50.759	25.483	17.029	12.793	10.248
18.3m MBG	B-16013 (10 million)	88.38	19.4	1.21	361.811	181.642	91.191	60.938	45.781	36.673
24.4m MBG	B-16011 (4 million)	98.3	25.6	1.18	238.428	119.699	60.093	40.157	30.169	24.167
24.4m MBG	B-16005 (10 million)	88.92	25.6	1.18	389.066	195.325	98.060	65.529	49.229	39.435
12.2m BGML	B-11003 (2million)	112.86	13.1	1.29	26.440	13.274	6.664	4.453	3.345	2.680
18.3m BGML	B-11004 (2 million)	117.38	19.4	1.21	30.446	15.285	7.674	5.128	3.852	3.086
24.4m BGML	B-11005 (2 million)	113.28	25.6	1.18	40.122	20.143	10.112	6.758	5.077	4.067

Table – 6 : Assessed fatigue life for different GMTs (MBG Loading) with sectional speed of 100 kmph, CDA with 100 kmph

GMA mf = 1
GMA fF = 1
Fatcat = 100 100 80 80

Std. Span	RDSO Drg. No.	Stress Range ó$_{Rmax}$ (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
					5	10	20	30	40	50
					0.721	0.830	0.956	1.038	1.101	1.152
12.2m MBG	B-16009 (4 million)	109.8	13.1	1.28	93.378	46.879	23.535	15.727	11.815	9.465
12.2m MBG	B-16012 (10 million)	88.8	13.1	1.28	263.261	132.166	66.352	44.340	33.311	26.684
18.3m MBG	B-16010 (4 million)	102.5	19.4	1.18	194.372	97.582	48.989	32.737	24.594	19.701
18.3m MBG	B-16013 (10 million)	78.9	19.4	1.18	697.510	350.174	175.800	117.479	88.258	70.698
24.4m MBG	B-16011 (4 million)	87.7	25.6	1.125	525.457	263.798	132.436	88.500	66.487	53.259
24.4m MBG	B-16005 (10 million)	79.31	25.6	1.125	858.574	431.034	216.394	144.606	108.637	87.024
12.2m BGML	B-11003 (2million)	104.7	13.1	1.28	39.619	19.890	9.986	6.673	5.013	4.016
18.3m BGML	B-11004 (2 million)	104.8	19.4	1.18	58.666	29.452	14.786	9.881	7.423	5.946
24.4m BGML	B-11005 (2 million)	101.1	25.6	1.125	88.272	44.316	22.248	14.867	11.169	8.947

Table – 7 : Assessed fatigue life for different GMTs (25 t Loading) with sectional speed of 100 kmph, CDA with 100 kmph

GMA mf = 1
GMA fF = 1
Fatcat = 100 100 80 80

Std. Span	RDSO Drg. No.	Stress Range ó$_{Rmax}$ (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
					5	10	20	30	40	50
					0.721	0.830	0.956	1.038	1.101	1.152
12.2m MBG	B-16009 (4 million)	109.7	13.1	1.28	90.297	45.332	22.758	15.208	11.425	9.152
12.2m MBG	B-16012 (10 million)	88.8	13.1	1.28	253.445	127.238	63.878	42.687	32.069	25.689
18.3m MBG	B-16010 (4 million)	107.5	19.4	1.18	139.052	69.809	35.046	23.420	17.595	14.094
18.3m MBG	B-16013 (10 million)	82.8	19.4	1.18	497.486	249.755	125.386	83.789	62.948	50.424
24.4m MBG	B-16011 (4 million)	92.7	25.6	1.125	317.497	159.395	80.022	53.475	40.174	32.181
24.4m MBG	B-16005 (10 million)	83.8	25.6	1.125	519.735	260.925	130.993	87.537	65.763	52.679
12.2m BGML	B-11003 (2million)	104.7	13.1	1.28	38.142	19.149	9.613	6.424	4.826	3.866
18.3m BGML	B-11004 (2 million)	109.9	19.4	1.18	41.991	21.081	10.583	7.072	5.313	4.256
24.4m BGML	B-11005 (2 million)	106.8	25.6	1.125	53.493	26.855	13.482	9.010	6.769	5.422

Table – 8 : Assessed fatigue life for different GMTs (25 t loading) with sectional speed of 75 kmph, CDA with 75 kmph

GMA mf = 1
GMA fF = 1
Fatcat = 100 100 80 80

Std. Span	RDSO Drg. No.	Stress Range ó$_{Rmax}$ (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
					5	10	20	30	40	50
					0.721	0.830	0.956	1.038	1.101	1.152
12.2m MBG	B-16009 (4 million)	101.15	13.1	1.28	134.198	67.372	33.823	22.602	16.980	13.602
12.2m MBG	B-16012 (10 million)	81.84	13.1	1.28	377.543	189.540	95.156	63.588	47.771	38.267
18.3m MBG	B-16010 (4 million)	100.2	19.4	1.18	196.021	98.409	49.405	33.015	24.803	19.868
18.3m MBG	B-16013 (10 million)	77.2	19.4	1.18	700.297	351.573	176.502	117.948	88.610	70.981
24.4m MBG	B-16011 (4 million)	87	25.6	1.125	432.826	217.294	109.089	72.899	54.766	43.870
24.4m MBG	B-16005 (10 million)	78.7	25.6	1.125	706.208	354.541	177.992	118.944	89.358	71.580
12.2m BGML	B-11003 (2million)	96.5	13.1	1.28	56.800	28.516	14.316	9.567	7.187	5.757
18.3m BGML	B-11004 (2 million)	102.5	19.4	1.18	59.018	29.629	14.875	9.940	7.468	5.982
24.4m BGML	B-11005 (2 million)	100.3	25.6	1.125	72.686	36.491	18.320	12.242	9.197	7.367

Table- 9 : Assessed fatigue life of open web girder 30.5m span, designed for BGML loading, BA-11122 at different speeds with full CDA@ 125kmph (Analysed for 25 t loading)

GMAmf = 1 gussets str. & X-gir
80 80
80 80

Member	Stress Range ó$_{Rmax}$ (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
				5	10	20	30	40	50
				0.721	0.830	0.956	1.038	1.101	1.152
L_0-L_1	79.84	31.926	1.03	430.078	215.914	108.396	72.436	54.419	43.592
L_1-L_2	79.84	31.926	1.03	430.078	215.914	108.396	72.436	54.419	43.592
L_2-L_3	93.89	31.926	1.03	194.896	97.845	49.121	32.825	24.661	19.754
L_0-U_1	62.06	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_1-L_2	121.8	25.54	1.07	45.406	22.795	11.444	7.648	5.745	4.602
L_2-U_3	110.7	19.16	1.07	72.402	36.348	18.248	12.194	9.161	7.339
U_1-U_2	82.54	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_2-U_3	82.54	31.926	1.03	Fatigue Assessment not necessary being in compression					
U1-L1& U3-L3	85.1	10.642	1.33	90.404	45.386	22.785	15.226	11.439	9.163
Stringer	94.11	5.321	1.37	47.854	24.024	12.061	8.060	6.055	4.850
X-girder	97.22	10.642	1.33	47.183	23.687	11.892	7.947	5.970	4.782

Table -10 : Assessed fatigue life of open web girder 30.5m span, designed for BGML loading, BA-11122 at different speeds with full CDA@ 100 kmph (Analysed for 25 t loading)

GMAmf	=	1	gussets	str. & X-gir
			80	80
			80	80

Member	Stress Range ó$_{Rmax}$ (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
				5	10	20	30	40	50
				0.721	0.830	0.956	1.038	1.101	1.152
L_0-L_1	75.61	31.926	1.03	561.026	281.654	141.400	94.491	70.988	56.865
L_1-L_2	75.61	31.926	1.03	561.026	281.654	141.400	94.491	70.988	56.865
L_2-L_3	88.91	31.926	1.03	254.315	127.675	64.097	42.833	32.179	25.777
L_0-U_1	58.77	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_1-L_2	110.37	25.54	1.07	73.465	36.882	18.516	12.373	9.296	7.446
L_2-U_3	103.46	19.16	1.07	100.736	50.573	25.389	16.966	12.746	10.210
U_1-U_2	78.16	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_2-U_3	78.16	31.926	1.03	Fatigue Assessment not necessary being in compression					
U1-L1& U3-L3	70.53	10.642	1.33	226.156	113.538	57.000	38.090	28.616	22.923
Stringer	86.22	5.321	1.37	73.388	36.843	18.497	12.360	9.286	7.438
X-girder	90.21	10.642	1.33	68.003	34.140	17.139	11.453	8.605	6.893

Table -11 : Assessed fatigue life of open web girder 30.5m span, designed for BGML loading, BA-11122 at different speeds with full CDA@ 75kmph (Analysed for 25 t Loading)

GMAmf	=	1	gussets	str. & X-gir
			80	80
			80	80

Member	Stress Range ó$_{Rmax}$ (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
				5	10	20	30	40	50
				0.721	0.830	0.956	1.038	1.101	1.152
L_0-L_1	71.37	31.926	1.03	743.641	373.334	187.427	125.248	94.095	75.374
L_1-L_2	71.37	31.926	1.03	743.641	373.334	187.427	125.248	94.095	75.374
L_2-L_3	83.93	31.926	1.03	336.981	169.176	84.932	56.756	42.639	34.156
L_0-U_1	55.48	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_1-L_2	103.64	25.54	1.07	99.884	50.145	25.175	16.823	12.639	10.124
L_2-U_3	96.92	19.16	1.07	138.565	69.565	34.924	23.338	17.533	14.045
U_1-U_2	73.78	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_2-U_3	73.78	31.926	1.03	Fatigue Assessment not necessary being in compression					
U1-L1& U3-L3	64.61	10.642	1.33	346.989	174.201	87.455	58.442	43.905	35.170
Stringer	78.33	5.321	1.37	117.257	58.867	29.553	19.749	14.837	11.885
X-girder	83.19	10.642	1.33	101.000	50.706	25.456	17.011	12.780	10.237

Table- 12 : Assessed fatigue life of open web girder 30.5m span, designed for BGML loading, BA-11122 at different speeds with full CDA@ 125kmph (Analysed for MBG loading)

GMAmf	=	1	gussets	str. & X-gir
			80	80
			80	80

Member	Stress Range σ_{Rmax} (N/mm²)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
				5	10	20	30	40	50
				0.721	0.830	0.956	1.038	1.101	1.152
L_0-L_1	75.03	31.926	0.96	821.411	412.377	207.028	138.347	103.935	83.257
L_1-L_2	75.03	31.926	0.96	821.411	412.377	207.028	138.347	103.935	83.257
L_2-L_3	88.31	31.926	0.96	370.663	186.086	93.422	62.429	46.901	37.570
L_0-U_1	58.38	31.926	0.96	Fatigue Assessment not necessary being in compression					
U_1-L_2	116.3	25.54	1.08	54.372	27.297	13.704	9.158	6.880	5.511
L_2-U_3	107.7	19.16	1.13	63.433	31.846	15.988	10.684	8.026	6.429
U_1-U_2	77.59	31.926	0.96	Fatigue Assessment not necessary being in compression					
U_2-U_3	77.59	31.926	0.96	Fatigue Assessment not necessary being in compression					
U1-L1& U3-L3	85.1	10.642	1.27	113.260	56.860	28.546	19.076	14.331	11.480
Stringer	83.15	5.321	1.34	97.589	48.993	24.596	16.437	12.348	9.891
X-girder	94.89	10.642	1.27	66.556	33.414	16.775	11.210	8.422	6.746

Table-13 : Assessed fatigue life of open web girder 30.5m span, designed for BGML loading, BA-11122 at different speeds with full CDA@ 100kmph (Analysed or MBG loading)

GMAmf	=	1	gussets	str. & X-gir
			80	80
			80	80

Member	Stress Range σ_{Rmax} (N/mm²)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
				5	10	20	30	40	50
				0.721	0.830	0.956	1.038	1.101	1.152
L_0-L_1	71.05	31.926	0.96	1071.850	538.106	270.148	180.527	135.624	108.641
L_1-L_2	71.05	31.926	0.96	1071.850	538.106	270.148	180.527	135.624	108.641
L_2-L_3	83.63	31.926	0.96	483.675	242.821	121.905	81.463	61.200	49.024
L_0-U_1	55.28	31.926	0.96	Fatigue Assessment not necessary being in compression					
U_1-L_2	109.61	25.54	1.08	72.608	36.452	18.300	12.229	9.187	7.359
L_2-U_3	101.02	19.16	1.13	86.713	43.533	21.855	14.605	10.972	8.789
U_1-U_2	73.47	31.926	0.96	Fatigue Assessment not necessary being in compression					
U_2-U_3	73.47	31.926	0.96	Fatigue Assessment not necessary being in compression					
U1-L1& U3-L3	78.53	10.642	1.27	167.708	84.195	42.269	28.246	21.221	16.999
Stringer	76.18	5.321	1.34	149.704	75.157	37.731	25.214	18.942	15.174
X-girder	88.32	10.642	1.27	94.452	47.418	23.806	15.908	11.951	9.574

Table- 14 : Assessed fatigue life of open web girder 30.5m span, designed for BGML loading, BA-11122 at different speeds with full CDA@ 75kmph (Analysed for MBG loading)

GMAmf =	1	gussets	str. & X-gir
		80	80
		80	80

Member	Stress Range σ_{Rmax} (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
				5	10	20	30	40	50
				0.721	0.830	0.956	1.038	1.101	1.152
L_0-L_1	67.07	31.926	0.96	1420.272	713.026	357.964	239.210	179.710	143.956
L_1-L_2	67.07	31.926	0.96	1420.272	713.026	357.964	239.210	179.710	143.956
L_2-L_3	78.94	31.926	0.96	640.901	321.754	161.532	107.944	81.095	64.961
L_0-U_1	52.19	31.926	0.96	Fatigue Assessment not necessary being in compression					
U_1-L_2	102.92	25.54	1.08	98.743	49.573	24.887	16.631	12.494	10.008
L_2-U_3	94.14	19.16	1.13	122.362	61.430	30.840	20.609	15.483	12.402
U_1-U_2	69.36	31.926	0.96	Fatigue Assessment not necessary being in compression					
U_2-U_3	69.36	31.926	0.96	Fatigue Assessment not necessary being in compression					
U1-L1& U3-L3	71.94	10.642	1.27	257.182	129.114	64.820	43.316	32.542	26.068
Stringer	69.20	5.321	1.34	239.291	120.133	60.311	40.303	30.278	24.254
X-girder	81.46	10.642	1.27	140.238	70.404	35.345	23.620	17.745	14.214

Table -15 : Assessed fatigue life of open web girder 30.5m span, designed for 25 t loading, BA-11679 at different speeds with full CDA@ 125kmph (Analysed for 25t loading)

GMAmf	=	1	
Fatcat	=	80 gussets	80 str. & X-gir
Fatcat/GMAmf	=	80	80

Member	Stress Range σ_{Rmax} (N/mm^2)	Loaded Length 'L' (m)	Loading factor, Lamda1	Design Life (years) for GMT & corresponding average route GMT factor (Lamda2)					
				5	10	20	30	40	50
				0.721	0.830	0.956	1.038	1.101	1.152
L_0-L_1	55.99	31.926	1.03	2201.999	1105.480	554.990	370.873	278.624	223.191
L_1-L_2	55.99	31.926	1.03	2201.999	1105.480	554.990	370.873	278.624	223.191
L_2-L_3	73.77	31.926	1.03	632.741	317.658	159.475	106.570	80.062	64.134
L_0-U_1	65.05	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_1-L_2	72.86	25.54	1.07	558.154	280.213	140.677	94.007	70.625	56.574
L_2-U_3	81.252	19.16	1.07	327.776	164.555	82.612	55.206	41.474	33.223
U_1-U_2	82.41	31.926	1.03	Fatigue Assessment not necessary being in compression					
U_2-U_3	82.41	31.926	1.03	Fatigue Assessment not necessary being in compression					
U1-L1& U3-L3	74.82	10.642	1.33	169.509	85.100	42.723	28.550	21.448	17.181
Stringer	79.49	5.321	1.37	324.480	162.900	81.781	54.651	41.057	32.889
X-girder	85.52	10.642	1.33	262.435	131.752	66.144	44.201	33.207	26.600

6.2 It is further noted that the new 25t loading has been permitted with a sectional speed of 75 kmph due to considerations of overall strength of the bridges. Accordingly, the fatigue life of bridges with new 25t loading at 75 kmph has been again worked out with reduced CDA value corresponding to 75 kmph and the results are given in Table – 8.

6.3 The analysis for standard Open Web Girders (Truss Type) has also been done for standard span of 30.5 m for varying speeds and the two loadings i.e. MBG Loading and 25 t loading. The results of analysis are shown in Table- 9 to Table - 15. The effect of reduction of speed and the difference in fatigue life of different members for a particular speed can be noted.

7.0 LIMITATIONS OF THE RESULTS OBTAINED

The results of analysis may be interpreted keeping in view the following:

- Assessment is based on Simplified Approach which has an overall conservative effect.
- Fatigue failure means that theoretically, the steel structure or any one of it's components has reached the specified limit state of fatigue. Although complete failure may not happen for some more time due to the reserve strength still available.
- The average GMT (say 50) is over the life span of the bridge which is not expected to be achieved even if the GMT presently being carried is more than it (say 50).
- The GMT may be comprised of no. of trains which may not give the maximum stress range e.g. passenger /empty goods trains.
- The average speed of the goods trains in many cases may be actually lower than 75 kmph. The location of the bridge is also important in this respect.
- Rigidity of end supports has not been accounted for in the analysis. It will reduce stress ranges actually coming.
- Fatigue Strength category ($\Delta\sigma C$) chosen may be conservative and require up-gradation.
- λ_1 values adopted are maxima of values worked out for different trains included in load model.
- CDA values adopted are extreme values as per Bridge Rules and actual values may be somewhat lower depending upon track maintenance standards.
- More refined estimate of Design life/Residual fatigue life can be made by detailed analysis.

8.0 CONCLUSIONS

8.1 Route GMT and sectional speed are important parameters which affect the design fatigue life considerably. The Effect of reducing CDA is to improve the design fatigue life by reducing the maximum design stress range and the reduction is substantial.

8.2 Plate girders designed for 2 million cycles as per existing fatigue criteria in IRS Steel Bridge Code gives very low estimate of fatigue life and the same need to be verified again using detailed fatigue life analysis with respect to train loads and actual GMT on the routes where these girders are provided.

8.3 The design life of Open web Girders is governed by the lowest estimated design life of its components. Usually the diagonal members and verticals are governing the design life which is considered acceptable as these members are either having reversal of stresses or a short base of Influence Line Diagram (ILD).

8.4 The design fatigue life of standard girders is found reduced as a result of running of 25t loading – 2008 vis-à-vis existing MBG loading. The amount of reduction depends upon the span length and the configuration of the bridge.

8.5 The effect of speed on design fatigue life can be mathematically evaluated with the help of new provisions and the design fatigue life can be significantly improved by either reducing the sectional speed or by improving the track maintenance over girder bridges.

8.6 The results of analysis on existing standard span shows that the proposed provisions are rational and capable to design new steel bridges on Indian Railways for the anticipated traffic densities and specified design life with respect to fatigue.

REFERENCES

1 Draft Correction Slip No. 18 to IRS Steel Bridge Code (sent to Railway Board for approval vide B&S Dte's letter No.CBS/PSB dated 04-05-2010.

2 IRS Code of Practice for the Design of Steel/ Wrought Iron Bridges (Steel Bridge code) Revised 1962, (with all the amendments).

3 IRS Bridge Rules (Revised -1964, Incorporating Correction Slip 1 to 41), B&S Directorate, RDSO, Ministry of Railways, Lucknow.

4 Design documents for various standard designs B & S Directorate, RDSO, Ministry of Railways, Lucknow.

STRESS INVESTIGATION TESTS OF PROTOTYPE SHELLS OF RAILWAY ROLLING STOCKS

L.M.Pandey* & R.K.Misra**

रेल वाहनों का बाह्य आवरण फेब्रीकेटेड संरचना होती है। प्रोटोटाइप के बाह्य आवरण पर वास्तविक सेवा दशाओं के सापेक्ष सिमुलेटेड वर्टीकिल एवं संकुचन भारों के पश्चात विकृति तथा प्रतिबल स्तरों हेतु परीक्षण किया जाता है। इस परीक्षण को प्रतिबल जांच परीक्षण कहा जाता है। वाहन को नियमित सेवा में लेने से पहले नमूने (प्रोटोटाइप) पर डिजाइन वैधीकरण परीक्षण किया जाता है। आरडीएसओ द्वारा पुर्जो पर उत्प्रेरक प्रतिबलो का पता लगाने हेतु स्ट्रेन गेज विधि काम में लाई जा रही है। आवरण के नमूने विश्लेषण द्वारा महत्वपूर्ण स्थानों का पता लगाया जाता है। तदनुसार गेज फिक्स किया जाता है। इस लेख में बाह्य आवरण (शेल) के महत्वपूर्ण क्षेत्रों पर विकृति एवं प्रतिबल स्तरों के आंकलन हेतु किए प्रतिबल जांच परीक्षण की विधि की विस्तृत व्याख्या की गई है।

Shells of Railway Vehicles are fabricated structures. The strength of prototype shells are tested for stress levels and deformation after simulating vertical and squeeze loads similar to the actual service conditions. This test is called Stress Investigation Test. This design validation test is carried out on the prototype before regular introduction of the vehicle in service. RDSO is using the strain gauge method to find out the induced stresses on the components. The critical locations are decided by Model Analysis of the shell and accordingly the gauge fixing is done. In this article the method of Stress Investigation Test as done for assessment of stress level and deformation on the critical areas of a shell is explained in detail.

1.0 INTRODUCTION

Railway vehicles, before being introduced in to service go through different tests/trials. Broadly these can be categorized as stationary and dynamic tests. Stress investigation tests are stationary tests which are carried out to check the structural strength of the body of a coach/ wagon to verify its structural integrity.

From design point of view, the body of coach/ wagon comprises of the under frame, the side walls, the end walls and the roof which together form a tubular structure. During the Stress Investigation Tests, vertical, compressive and tensile loads are applied on the shells by mounting the test shell on specially fabricated rigs. This setup is used to simulate different types of loads on the test shell as per actual service conditions. In this article we will discuss the procedure adopted for conducting the stress investigation of prototype shells on Indian Railways.

2.0 PURPOSE OF THE TEST

Stress investigation tests are also called "Squeeze Tests" since the prototype shell is subjected primarily to squeeze loads. The purpose of these tests is to check that there is no danger of permanent deformation of the shell/body or its individual component parts and that no fracture will occur in the event of maximum loadings that may occur exceptionally in service. The objectives of stress investigation tests are as follows;

- Validation of structural design which is done with the help of FEM and other analysis softwares.
- Assessment of stress levels at different critical locations on the body/shell and underframe under various loads.
- Measurement of deformation at critical locations under various vertical loads, compressive loads and combination of both.
- Visual examination of the shell/body for any permanent deformation or crack after removal of loads.

3.0 RESULTS EXPECTED FROM STRESS INVESTIGATION TESTS

The following results indicate the success of the tests;

- The recommended stress values at any point have not exceeded the permissible/specified limits.
- After removal of the load, there is no permanent deformation of the shell or any of the components.
- The magnitude of parameters measured is comparable with results obtained by FEM.

4.0 METHODOLOGY OF STRESS INVESTIGATION TEST

4.1 Principle of Stress Measurement

In a balanced Wheatstone bridge connected with resistors R_1, R_2, R_3 and R_4, the electrical output e_o is zero.

By applying Ohm's law, we get,

$R_1/R_4 = R_2/R_3$ ……(1).

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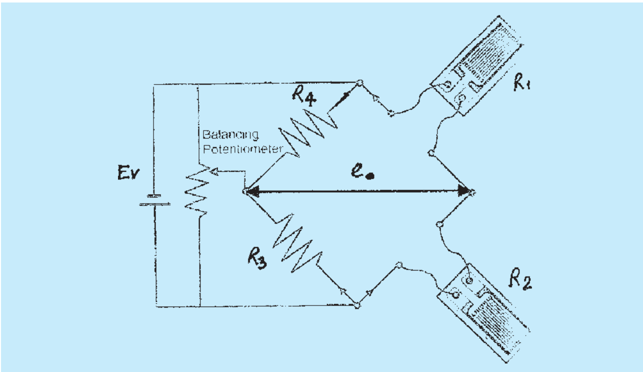

Fig.1

R_1 becomes an active arm of the bridge if resistor R_1 is replaced with a strain gauge which is bonded on the material which is under strain. In unbalanced condition of the bridge when active arm resistance is changed by dR_1, by applying Kirchhoff's law,

$$e_o = \frac{E_v \times R_1 \times R_2 \times dR_1}{(R_1+R_2)^2 \times R_1} \qquad (2)$$

Gauge factor of the strain gauge

$(GF) = [dR/R]/[dl/l]$

where, l is length of gauge filament.

Strain (e) = dl/l and thus,

$$dR/R = GF \times e \qquad (3).$$

Substituting dR/R and $R_1=R_2=R$ in equation (2), we get,

$$e_o = \frac{Ev \times GF \times e}{4} \qquad (4).$$

The Resistance of most conductors changes with temperature. Also, thermal coefficient of expansion of the strain gauge filament is different from that of the structure to which it is bonded. Thus, strain gauge is likely to be subjected to false strain indications with temperature. The temperature compensation is accomplished by a second dummy strain gauge on an unstrained piece of the same metal as that to which the active gauge is bonded. This dummy gauge is either R_2 or R_4 so that ratio (1) is undisturbed, i.e.,

$$[R_1+dR_1]/R_4 = [R_2+dR_2]/R_3.$$

In case of four active arms of the bridge, by applying Kirchhoff's law, we get

$$e_o = \frac{(E_v \times R_1 \times R_2)\,(dR_1/R_1 - dR_2/R_2 + dR_3/R_3 - dR_4/R_4)}{(R_1+R_2)^2} \qquad (5).$$

Substituting $R_1=R_2=R_3=R_4=R$ in equation (5),

$$e_o = \frac{Ev \times GF \times e \times n}{4} \qquad (6).$$

Where n is the number of active arms. In this case, R_2 and R_4 accomplish the temperature compensation of R_1 and R_3.

4.2 Actual Instrumentation

Initially, the prototype test shell is kept on Test Rig and active strain gauges (R_1) are fixed on the critical locations as per test scheme. This is followed by same no. of dummy strain gauges (R_2) being fixed on the same type of unstrained piece of material plate inside a junction box or as per suitability for temperature compensation. Resistor R_3 & R_4 are provided in the Data Acquisition system itself and complete the bridge. The connections and wiring of the active gauge and dummy gauge to the equipment used for recording is then completed.

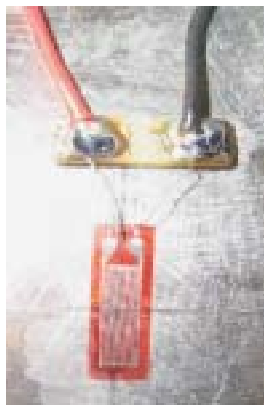

Fig.2:Enlarged View of a linear strain gauges fixed on a surface

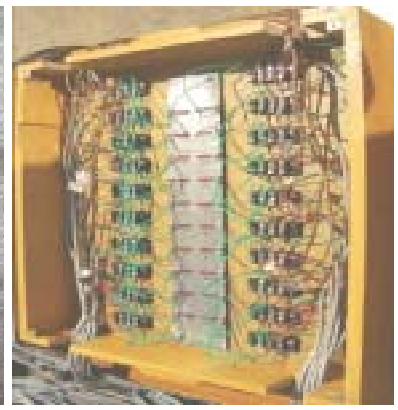

Fig.3:View of a Junction box with strain gauges fixed on dummy plate

For proper temperature compensation the dummy boxes are kept closer to the active gauge to avoid temperature difference.

In the latest data acquisition systems available with Testing Directorate, the software in the system is able to convert the voltage output of the bridge directly into the stress values by feeding the Young's Modulus of the material in to the system. The same was previously calculated manually since the output of old APEX unit was the voltage drop e_o in mV. The detailed calculation procedures with both new and old systems are described in Para 4.5.1.

4.3 Loading Schemes

Stress tests are carried out by simulation of vertical and squeeze loads on the shell as per the requirement of Test Scheme. The dynamic augmentation, shock and factor of safety are taken into the account for deciding these loads. Vertical loads are normally applied in the steps given below;

- Bare weight of empty shell
- Pay load of the Coach/Wagon
- Pay load + Extra load (considering overload, dynamic augmentation of springs, shock load etc.)

Squeeze loads are applied for each of the vertical loading conditions and in steps to avoid any serious damage of rig or shell caused by sudden application. For example for the application of 250t squeeze load, we start in steps like 150t, 200t and 250t and closely monitor the output of those channels where stress values are maximum so that failure of any component can be minimized.

Test rigs are specially fabricated structure with trestles having arrangement for loading and unloading of the shells. The squeeze loading **hydraulic jack**s of required capacity are mounted on the rigs according to the load application point e.g. CBC, side buffers etc.

Fig.4:View of BOXNHL Wagon on the test rig

Fig.5:Arrangement showing application of squeeze load at CBC with 300t capacity hydraulic jack

Vertical loads are applied on the floor of the shells. Specially fabricated vertical loading platforms are placed on the floor for even load distribution and for lifting and lowering of these loads during the course of test.

The lifting of vertical loads is required after each load series to relieve the stresses on the shell and to reset the gauges for the next reading. This is done by lifting the loading platform by a set of hydraulic jacks kept below the shell which push the platform through holes cut on the floor.

4.4 Test Procedure

After completing the instrumentation as per Para 4.2 above, a squeeze load of 50t is applied on the prototype for few minutes to relieve the residual stresses left in the structures during fabrication stage. Thereafter after releasing this load balancing of the data recording system is done. For balancing i.e. zero setting of the system the shell should be in no load condition i.e. the vertical loading platform should be lifted and squeeze load should not be applied.

Balancing of the recording system is followed by adjustment of deformation measurement sensors/dial gauges on specially fabricated stands. After that the test series is started as per the test scheme.

Two set of readings are taken for every series. If both are not found to be consistent, a third reading of the same series is taken to get consistency. After completion of every set of readings, the zero setting of recording equipment and adjustment of dial gauges are done.

4.5 Test Equipments Used by RDSO for Stress Investigation Tests

4.5.1 Measurement of stress values: Strain is measured by measuring the change in resistance of the active gauge i.e. the gauge fixed on the component material. The gauge factor of strain gauge and the Young's Modulus value of the component material are used to calculate the actual stress in the component after applying a known value of horizontal squeeze load and vertical load as per the test scheme. The equipments used for this measurement by RDSO are described below:

4.5.1.1 Apex Unit is used for half-bridge completion and for switching channels. This instrument comprises of two separate strain gauges of 120 Ω forming dummy arms of the Wheatstone bridge. The other half of the bridge is formed by the gauge cemented on the structure under test and compensating gauge cemented on a steel plate in the junction box kept in the vicinity of active gauge. Suitable variable resistance is provided across the second half of the bridge for accurate initial balancing. The voltage of the bridge is provided by a dc power supply (5V). The strain output of the bridge is read on digital multimeter (DMM) in terms of milli-volts and this value is used to compute the stress in kg/mm².

Computation of the stress from the strain experienced by the gauge on a location is done on the principle of inducing a "virtual strain" by changing the resistance of the active arm by using a shunt and using the equation:

$$\text{Gauge factor} = \frac{\delta R/R}{\text{Strain}}$$

To calculate this virtual strain this is converted to stress and equated with the measured mV.

Gauge resistance (R)	350 ± 1 Ω
Gauge Factor (GF)	2.10±1%
Shunt Resistance (R_{sh})	240 K Ω

Req is equivalent resistance in circuit when bridge arm is shunted with R_{sh}

$1/R_{eq} = 1/R + 1/R_{sh}$

So, $R_{eq} = R x R_{sh} / (R + R_{sh})$

Fig.6:APEX unit with accessories

Change in resistance $\delta R = R - R_{eq}$

$= R - [R x R_{sh}/(R + R_{sh})]$

$= R_2 / (R + R_{sh})$

Gauge Factor (GF) $= (\delta R/R) / (\delta L / L)$

$= [R/(R+R_{sh})]$ / Strain

Strain (e) $= R / [GF (R + R_{sh})]$

= 350 / [2.10 (350+ 240000)]

= 6.934x10-4

Modulus of Elasticity for IS 2062: Fe 410Cu WC, E = 2.04x104 kg/mm^2

Shunt Stress (P)= e x E

= 6.934x 10 –4 x 2.04 x 104 kg/mm^2

= 14.145 kg/mm^2

Thus, for shunt value of 240 KΩ, stress is 14.145 kg/mm^2

The system displayed a reading of – 1.81 mV when 240 KΩ resistance was shunted across the Wheat Stone Bridge. Thus –1.81 mV reading on system corresponds to 14. 145 kg/mm^2 stress value as calculated above. Hence 1 mV reading will correspond to a stress value of 7.8149 kg/mm^2 assuming the relationship to be linear.

4.5.1.2 The measurement of stresses using strain gauges at the various locations is also done by using DEWETRON make DEWE-2500 DAQ system. Strain gauge bridge measurement module DAQP-BRIDGE-B signal conditioners are used for excitation and amplification of strain gauge bridge

Fig.7:Dewetron system

signals for the DAQ system. The 'E' (Young's Modulus) value of material is input to the system and the software directly records stress readings. This system can be used for stress measurement up to 40 channels simultaneously.

4.5.1.3 The latest system being used for stress measurement is IOtech Strain Book Model 616.

Fig.8:IOtech system (Laptop with waveView software + strain book/616)

Fig.9:Magnetic base dial gauge & laser sensor in position

It has capacity to record 56 channels simultaneously with use of one strain book 616. 7 extension modules can be connected in one strain book 616. The output of the system is strain value in micro strain. Total 80 channels can be recorded using this equipment.

4.5.2 Measurement of deformation: The deformation in the prototype shells are conventionally measured with the help of dial gauges with magnetic base. The view of a dial gauge placed in location is shown above. Presently PC based laser beam sensors for deflection measurement are also being used in place of dial gauges.

The criterion of maximum deflection under load permissible for a structure is decided by designer. However, the requirement is that the shell should come to its original condition/shape after removal of the loads.

5.0 COMPARISON WITH FEA RESULTS

A latest example of the comparison of results of stress investigation test with designed parameter is as follows;

On the basis of FEA done by simulating pay load and 250t squeeze load at CBC level on the shell of the BOXNHL wagon, Wagon Design Directorate prepared a drawing numbered WD- 08064-S-01 for the strain gauge locations. Accordingly, the gauges were fixed and the tests were completed for the prototype BOXNHL wagon. The results indicated the maximum values at the locations as indicated in the FEA results.

It was found that the area near center sill and body bolster joint (shown by red) is a high stress concentration area. The strain gauges fixed in this high stress concentration area showed maximum stress values during all the stress investigation tests carried out.

This demonstrates that the results obtained by stress investigation tests are compatible with the FEA results. This ensures the significance of both the techniques adopted for validation of new design. The FEA results along with stress levels in complete structure of BOXNHL wagon is reproduced below.

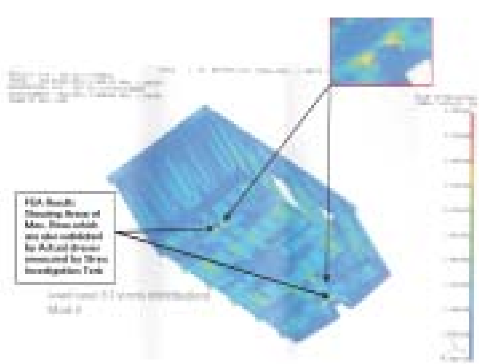

Fig.10:FEA result of a BOXNHL wagon showing stress concentration areas

6.0 STRESS INVESTIGATION TESTS CONDUCTED BY RDSO IN RECENT PAST

It is now mandatory for every new design of wagons and coach to pass Stress investigation test at prototype stage before their introduction in actual service. Some of the important design prototypes of wagons and coaches tested recently by Testing Directorate are given below:

- BOXNHL and BCNHL wagons prototype manufactured by following Wagon Builders:
  - M/s Texmaco, Kolkata
  - M/s Besco, Kolkata
  - M/s HEI, Kolkata
  - M/s Jupiter, Kolkata
  - M/s Titagarh, Kolkata
  - M/s Modern, Ghaziabad

Fig.11:View of OHE tower car wagon undergoing stress investigation tests

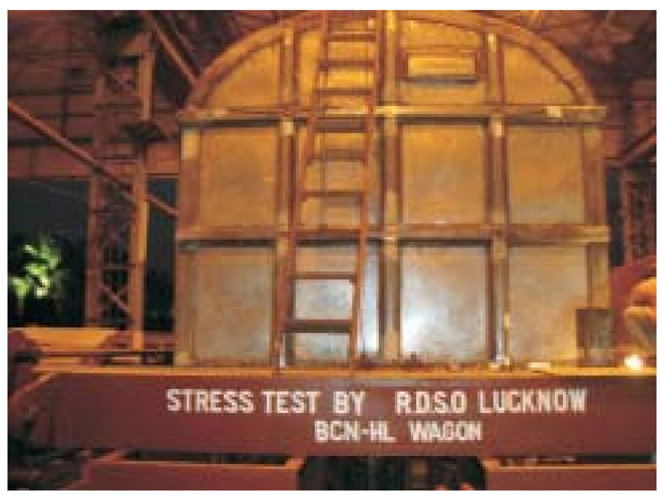

Fig.12:End view of loaded BCNHL wagon

- OHE Tower Car Wagons manufactured by:
  - M/s Phooltas, Haridwar
  - M/s OEPL, Hyderabad
- Kolkata Metro Trailer Coach Shell Manufactured by ICF/Chennai

Fig.13:View of Kolkata Metro trailer coach shell

Fig.14:View of AC EOG double decker coach shell

- BG AC EOG Double Decker Coach shell manufactured by RCF/Kapurthala.

REFERENCES

1. UIC Code_566/OR on loadings of Coach Bodies and their Components.
2. RDSO Report No. MT-334.
3. RDSO Report No. MT-886/F, MT-890/F, MT-891/F, MT-911/F, MT-912/F, MT-920/F and MT-928/F.

★☆★

SUITABILITY OF USE OF FLY ASH IN RAILWAY EMBANKMENT

Rajesh Agarwal* & S.K.Gupta**

भारत में इम्बैंकमेंट कांस्ट्रक्शन के लिये स्ट्रक्चरल -फिल मैटीरियल की भारी मांग है। कांस्ट्रक्शन साइट पर उपयुक्त स्वायल के उपलब्ध न होने के कारण शहरी क्षेत्रों में समस्या काफी गंभीर हो जाती है। फ्लाई -ऐश जैसा इंडस्ट्रियल वेस्ट के फिल -मैटीरियल को रेलवे इम्बैंकमेंट कांस्ट्रक्शन में प्रयोग इसका एक विकल्प हो सकता है। पर्यावरण तथा वन मंत्रालय भारत सरकार द्वारा रोड-इम्बैंकमेंटमें फ्लाई ऐश के अनिवार्य प्रयोग के लिये गजट नोटिफिकेशन न. 773 जारी किया गया है। इस नोटिफिकेशन के अनुसार आई आर सी स्पेसिफिकेशन न. एस पी : 58/2001 में यथा उल्लेखनीय इंडियन रोड कांग्रेस (आईआरसी) द्वारा जारी दिशा निर्देशों/ स्पेसिफिकेशनों के उल्लंधन में कोई एजेंसी, व्यक्ति या संगठन किसी थर्मल पावर प्लांट के 100 किमी के रेडियस के अंदर सड़क निर्माण या संगठन किसी फ्लाई ओवर इम्बैंकमेंट के लिये न तो कोई कांस्ट्रक्शन करेगा और ही कोई डिजाइन को एप्रूव करेगा अर्थात यह रोड - प्राधिकारियों को थर्मल प्लांटो के 100 किमी के अंदर कांस्ट्रक्शन के तहत रोड -इम्बैंकमेंट में फ्लाई ऐश के प्रयोग को प्राधिकृत करता है। इस दिशा निर्देश का कोई उल्लघंन केवल तकनीकी आधार पर ही किया जा सकेगा इस लेख में विभिन्न थर्मल पावर प्लांटों से एकत्र की जा रही फ्लाई ऐश की प्रापटी तथा इसके प्रयोग की कोई सीमाये, यदि कोई हो पर रेलवे हैं इम्बैंकमेंट कांस्ट्रक्शन हेतु विचार किया गया है।

The requirement of structural fill materials for embankment construction is in great demand in India. The problem is more acute in urban areas due to non availability of suitable soil in vicinity of construction site. The use of industrial waste like fly ash as a fill material for construction of Railway embankment can be one option to explore. Ministry of Environment & Forest, Govt. of India has brought out a Gazette Notification No. 773 for compulsory use of fly ash in road embankments. According to this notification no agency, person or organization shall, within a radius of 100 kilometers of a thermal power plant undertake construction or approve design for construction of roads or flyover embankments in contravention of the guidelines/specifications issued by the Indian Road Congress (IRC) as contained in IRC specification No. SP: 58 of 2001, thus it enforce Road authorities to use fly ash in road embankments under construction with in 100 km of Thermal plants. Any deviation from this direction can only be agreed to on technical reasons. In this paper properties of fly ash collecting from different Thermal power plant have been discussed and limitation of it uses if any, for construction of Railway embankment.

1.0 INTRODUCTION

There is a shortage of topsoil in most urban areas for filling low-lying areas, as well as for constructing road/ rail embankments. The other option is to use waste materials arising from different sectors such as domestic, industrial and mining etc. Coal ash / fly ash is one such industrial waste arising out of thermal power plants. Around 110 million tonnes of fly ash get accumulated every year at the thermal power stations in India. Fly ash is considered as a by product which can be used for many applications. Fly ash utilization in the country rose from 3 per cent (of 40 million tonnes) of fly ash produced annually in 1990s to about 32 per cent (of 110 million tonnes) of fly ash produced annually. Out of this total utilisation, about 22 per cent, amounting to 7.75 million tonnes, is used in the area of roads embankments. Fly ash is mainly used in cement production, bricks manufacturing, soil improvement for agricultural purposes and in embankment of roads etc. The use of fly ash in construction of roads embankments has vast proposition for its bulk utilization. Central Road Research Institute (CRRI), New Delhi, chosen as the 'Nodal Agency' for this activity, has undertaken many demonstration projects. Some of these are jointly with Fly Ash Mission (Presently Fly Ash Utilisation Programme). As a result of experience gained through these projects, specifications for construction of road embankments and guidelines for use of fly ash for rural roads were compiled and have since been published by the Indian Roads Congress.. This paper, the focus is on the use of coal/fly ash as a engineering fill material for construction of Railway embankment.

2.0 PRODUCTION OF VARIOUS TYPES OF COAL ASH IN THERMAL POWER PLANT

2.1 Fly Ash

This ash comprises about 80% of total ash produced in Thermal plant. It is collected from different fields of Electro Static Precipitators (ESP) in dry form. This is characterized by comparatively lower carbon content and higher fineness. Fineness of fly ash is more in subsequent fields of ESP as compared to initial fields.

2.2 Bottom Ash

This bottom ash is collected at the bottom of boiler furnace as a resultant of coal burning activity. This is

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characterized by comparatively higher carbon content and coarse size. This comprises about 20% of total ash produced in a station.

2.3 Pond Ash

The slurry formed after mixing fly & bottom ash with water is pumped to the nearby ash ponds wherein water gets drained away. The ash thus stored in ash ponds is called Pond ash. Thus Pond ash is a mixture of bottom ash and fly ash.

3.0 AVAILABILITY OF COAL ASH

Coal ash is available in large volume in coal based thermal power plants. Some coal based plants are listed below from where coal ash for railway embankment can be taken:

Singrauli Super Thermal Power Station, Korba Super Thermal Power Station, Ramagundam Super Thermal Power Station, Farakka Super Thermal Power Station, Vindhyachal Super Thermal Power Station, Rihand Super Thermal Power Station, National Capital Power Station, Feroz Gandhi Unchahar Super Thermal Power Station, Badarpur Super Thermal Power Station, Kahalgaon Super Thermal Power Station, Talcher Kaniha Super Thermal Power Station, Talcher Thermal Power Station, Tandar Thermal Power Station, Simhadri Super Thermal Power Station.

4.0 ENGINEERING PROPERTIES OF COAL ASH

Some coal ash samples (Fly ash, Bottom ash & Pond ash) from different thermal power plants were tested in GE Lab, RDSO for suitability of coal ash to be used as a fill in railway embankments Test results of these samples are tabulated below:

Table -1

S.No.	Name of Thermal Power	Mechanical Analysis * (In %)				Percentage Passing	Uniformity Coefficient (Cu)	Coefficient of Curvature (Cc)	Consistency limit			Tri-axial shear/ direct shear test				Compaction Characteristics**		Sp. Gravity
		Gravel	Sand	Silt	Clay				Liquid Limit	Plastic Limit	Plasticity Index	Cohesion C' kg/cm²	Angle of Internal friction φ'	Cohesi on C kg/cm²	Angle of Internal friction φ	OMC (%)	MDD (gm/ cm³)	
1	NTPC Vidhya Nagar (M.P.) Fly Ash	00	20	80	00	80	10.47	0.76	NP	NP	NP	-	-	-	-	13.5	1.51	2.19
2	NTPC Vidhya Nagar (M.P.) Pond Ash	01	72	27	00	27	4.52	1.47	NP	NP	NP	-	-	-	-	21.0	1.31	2.06
3	Singrauli super thermal power station (fly ash)	06	56	38	00	38	66.67	9.80	NP	NP	NP	0.02	33.83	-	-	22.5	1.28	1.82
4	Singrauli super thermal power station (bottom ash)	09	84	07	00	07	3.66	1.47	NP	NP	NP	0.00	35.33	-	-	25.0	1.27	2.13
5	Kolaghat thermal power (fly ash)	00	61	39	00	39	-	-	NP	NP	NP	0.024	33.65	0.10	11.2	19.2	1.26	2.2
6	Barauni thermal power (fly ash)	00	94-95	05-06	00	05-06	3.05-3,38	1.23-1.47	NP	NP	NP	0.012	33.5-33.65	0.0-0.01	24	17.60-19.45	1.641-1.660	2.34-2.41
7	Uchahar thermal power (fly ash))	00	16-30	70-84	00	70-84	8.54-11.96	0.63-1.37	NP	NP	NP	0.0143	32.98	-	-	18-24.5	1.22-1.42	-
8	Badarpur thermal power (bottom ash)	00-06	80-92	03-17	00	03-17	3.54-5.0	0.74-1.31	NP	NP	NP	-	-	-	-	-	-	-

*As per IS Code 2720 (Part-4) 1985

** As per IS Code 2720 (Part-8) 1983

Table -2

S.No.	Name of Thermal Power	Pre-consolidation pressure kg/sqcm	Compression Index (C_c)	Initial void ratio (e_0)	Coefficient of consolidation (Cv)		
					2 kg/cm²	4 kg/cm²	8 kg/cm²
1	NTPC Vidhya Nagar (M.P.) Fly Ash	-	-	-	-	-	-
2	NTPC Vidhya Nagar (M.P.) Pond Ash	-	-	-	-	-	-
3	Singrauli super thermal power station (fly ash)	1.00	0.2086	0.5795	0.1671	0.2169	0.1702
4	Singrauli super thermal power station (bottom ash)	0.90	0.2428	0.4894	0.1394	0.1466	0.2291
5	Kolaghat thermal power (fly ash)	0.75	0.1107	1.1275	0.1196	0.1849	0.2552
6	Barauni thermal power (fly ash)	0.95-1.02	0.0674-0.0719	1.0870-1.3154	0.1302-0.3629	0.2627-0.3581	0.2515-0.3509
7	Uchahar thermal power (fly ash)	-	-	-	-	-	-
8	Badarpur thermal power (bottom ash)	-	-	-	-	-	-

5.0 DISCUSSION ON TEST RESULTS

Grain size distribution indicate that percentage of fines in bottom ash in the range of 3-17% which is better material for construction of embankment but its availability is too much less in every thermal power plant for construction of embankment where as pond ash has more fines than bottom ash but less fines than fly ash and available in bulk for construction of embankment. However, the properties of coal ashes vary in different thermal power stations. Test results indicate that coal ash contain most of sand and silt particles and non plastic in nature. OMC & MDD test results indicate that coal ash having very high OMC and low MDD value with respect to soil. It is lighter than soil and very porn to erosion Therefore, special construction activity is required for construction of embankment. Fugitive dust emission occurs at construction sites as well as during transportation in dry month due to wind erosion from ash, which is spread, as well as stock piled at site which created serious wind pollution at construction site. Hence preventive and corrective measures should be taken to control this menace. On daily basis, it should be ensured that all dumpers carrying coal ash should fully covered by tarpaulin. Overloading of dumpers should strictly not allowed. Continuous water sprinklers should be carried out and providing intermediate earth cover. Shear parameter indicate that fly ash having very low cohesion value. Consolidation test results indicate that fly ash is having high void ratio as compare to ordinary soil. Uniformity coefficient of bottom ash is less than 7 indicate that the material is not well graded.

6.0 DESIGN OF FLY ASH EMBANKMENTS

The design of fly ash embankment is basically similar to design of soil embankment. The design process for embankments involves the following steps:

- Site investigations
- Characterization of materials
- Detailed design

6.1 Site Investigations

The following information concerning the site and surrounding areas must be collected:

- Topography
- Hydrology
- Subsoil investigations

6.2 Characterisation of Materials

The materials to be used in embankment construction should be characterized to determine their physical and engineering properties. If fly ash/Pond ash is to be used, the following information is required for approval before commencement of work :

- Particle size analysis

- OMC & MDD value determined by heavy compaction.
- Densities of fly ash - density lower than 0.9 gm/cc not suitable for embankment construction.
- Shear strength parameters – required for evaluation of the stability of proposed slopes and the bearing capacity of foundations located and the fill.
- Compressibility characteristics - required for predicting the magnitude and duration of the fill settlement.
- Permeability and capillarity - to assess seepage and to design drainage system.
- Specification for compaction of the fill material.
- Position of water table - High water table should be lowered by providing suitable drains.
- Details of intermediate horizontal soil layers between which ash is to be sandwitched.

6.2.1 General recommendations by IRC on characterisation of materials

- Fly ash to be used as fill material should not have soluble sulphate content exceeding 1.9 gm. per litre (expressed as SO_3) when tested according to BS: 1377.
- Coal used in Indian thermal power plants has high ash content. As a result, enrichment of heavy metal is lower as compared to fly ash produced by thermal power plants abroad.

6.3 Detailed Design

The design of fly ash embankment is similar to earthen embankments. Sri Manoj Dutta in his paper "Use of Coal Ash in Embankment Stability Analysis and Design Consideration" published in Journal of Civil Engineering & Construction Review, April 1999 and "Engineering properties of Coal Ash" published in Journal of Indian Geotechnical Conference –1998 studied behavior of coal ash in embankment. The brief details of his paper are given below:

The use of bottom ash in embankment construction results in slope 2:1 being stable. These slopes are much steeper than slopes, which are stable when pond ash or fly ash is used.

The use of pond ash yields stable embankment slope of 2.5:1 (for ru =0 case)and 3:1(for ru =0.2 case)

Fly ash, which is a poorly draining material and has low strength, yields the least embankment slopes (4:1 for ru =0.2) for a factor of safety of 1.5.

- Special emphasis is required with respect to provision of earth cover.
- The thickness of side cover would be typically in the range of 1 m to 3 m.
- For embankment upto 3 m height, in general, the earth cover thickness about 1 m is sufficient.
- The side cover should be regarded as a part of embankment for design analysis.
- The FOS for embankments constructed using fly ash should not less than 1.25 under normal serviceability conditions.
- Intermediate soil layers are often provided in the fly ash embankment for ease of construction to facilitate compaction of ash and to provide adequate confinement.
- Properly benched and graded slopes prevent the erosion of fly ash particles.

6.4 Special Design Features of Embankment Constructed with Ash

- Fugitive dust emission occurs at construction sites during hot dry month due to wind erosion from ash, which is spread, as well as stock piled at site. This has to be avoided by
  - Suspending construction during hot dry months.
  - Providing continuous water sprinklers.
  - Providing intermediate earth cover.
- The possibility of surface water runoff pollution due to erosion by rainwater during construction in the monsoon month has to be recognized and appropriate design measures adopted. "Contained- cells" construction technique can also reduce surface water pollution.
- The stability of side slopes of thick fills has also to be ensured against long-term wind erosion and water erosion (in the absence of slope maintenance after construction) by providing self sustaining erosion control measures such as thick soil covers with side lopes with turfing.
- For embankment which are likely to experience ponding of water during monsoon months, well designed slope protection measures (such as stone pitching/rip rap) are required with proper toe protection.
- Compactibility of wet ash during monsoon months under condition of excess moisture has to be established.
- To preclude the possibility of piping of ash in

condition of seepage through ash, properly designed filters and drains (both internal & external) have to be provided.

7.0 GENERAL POINTS OF ROAD EMBANKMENT CONSTRUCTION USING FLY ASH

Successful field trials have shown the suitability of fly ash as a fill material for construction of road embankments. Both reinforced as well as un-reinforced type of embankments have been constructed using fly ash. Reinforced embankments, popularly known as Reinforced Earth walls (RE walls) are used in urban areas for approaches to flyovers and bridges. RE walls have several advantages like faster rate of construction, economy, aesthetic look and saving the land required for construction of an unreinforced embankment. Fly ash is an ideal backfill material for RE wall construction because of its higher angle of internal friction and better drainage property. Geosynthetic materials like geogrids or geotextiles can be used as reinforcement for construction of reinforced fly ash embankments.

The most distinguishing feature of un-reinforced fly ash embankment would be use of fly ash as core material with earth cover. In case of un-reinforced embankments, side slope of 1:2 (Vertical: Horizontal) is generally recommended. Providing good earth cover using loamy soil should protect the slopes of the embankments. The thickness of side cover would be typically in the range of 1 to 3 m. The thickness of cover depends on the height of the embankment, site conditions, flooding if expected, etc. This cover material can be excavated from the alignment itself and reused as shown in the Fig. 1 below.

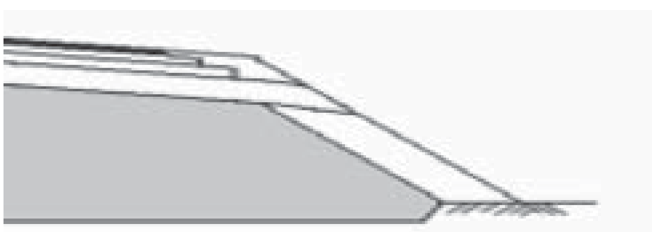

Fig. 1 : Excavation of earth from alignment of embankment for providing side cover

Stone pitching or turfing on this cover is necessary to prevent erosion due to running water. Intermediate soil layers of thickness 200 to 400 mm are usually provided when height of embankment exceeds 3 m. These intermediate soil layers facilitate compaction of ash and provide adequate confinement. Such intermediate soil layers also minimize liquefaction potential. Liquefaction in a fly ash fill generally occurs when fly ash is deposited under loose saturated condition during construction. To avoid the possibility of any liquefaction, fly ash should be properly compacted to at least 95 per cent of modified proctor density and in case water table is high, it should be lowered by providing suitable drains or capillary cut-off. Fly ash can be compacted using either vibratory or static rollers. However vibratory rollers are recommended for achieving better compaction. Compaction is usually carried out at optimum moisture content or slightly higher. The construction of fly ash core and earth cover should proceed simultaneously. High rate of consolidation of fly ash results in primary consolidation of fly ash before the construction work of the embankment is completed. The top 0.5 m of embankment should be constructed preferably using selected earth to form the subgrade for the road pavement.

7.1 Earlier Fly Ash Embankment Projects

Delhi PWD in association with CRRI pioneered in the construction of first **reinforced flyash approach** embankment on one side of the slip roads adjoining NH-2 in the Okhla fly over project. The length of the approach embankment is 59 m while the height varied from 7.3 m to 5.3 m. Geogrids were used for reinforcement of fly ash and a total quantity of about 2700 cum of ash from Badarpur thermal power plant was used for filling. The flyover was opened to traffic in January 1996.

First **un-reinforced fly ash** embankment in the country was constructed for eastern side approach of second Nizamuddin Bridge Project. A typical cross-section of the embankment shown in Fig. 2 below. Pond ash produced at nearby Indraprastha Power Station was used for construction. The project is unique of its kind, since pond ash has been used for construction of high embankment in flood zone. A total quantity of about 1.5 lakh cubic metres of pond ash was used in this project. CRRI were the consultants for this project and provided design of the embankment and were associated for quality control supervision during construction. The project was completed and the road section opened to traffic in September 1998. The experiences gained during this project led to formulation of Guidelines on use of fly ash for embankment construction.

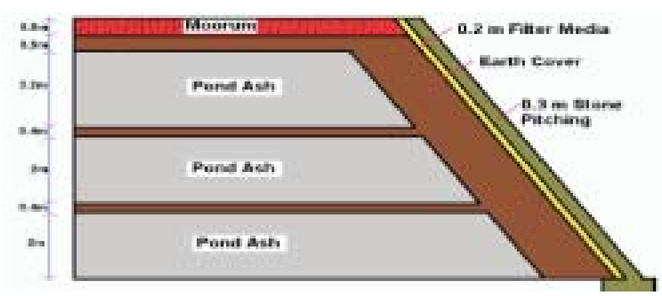

Fig. 2: Cross-section of fly ash embankment

7.2 Recent Experiences of Using Fly Ash for Road Embankment

Brief details of some of the projects executed in the recent past are given below:

7.3 Use of Pond Ash for Road Embankment on NH-6

As part of ongoing National Highway Development Programme, four-laning work of NH-6 from Dankuni to Kolaghat near Kolkata in West Bengal was taken up. The height of the embankment on this road section varied from 1.5 m to 4 m and requirement of earth fill was approximately 20 million cubic metres. However, good earth was not available near the proposed embankment site and the lead would be more than 100 km. This was leading to enormous increase in the project cost and also resulting in delays in the completion of the project. Hence the task on evaluating pond ash as alternative construction material was taken up. Required quantity of pond ash was available near the site at Kolaghat Power Plant. The pond ash samples collected from the Kolaghat power plant and bottom ash from Budge-Budge power plant (Kolkata) were tested in the laboratory to determine their engineering properties. The properties of pond ash, local soil and local sand are given in table below:

Table -3

Property	Local Sand	Bottom ash from Budge -Budge Thermal Power Plant	Pond ash from Kolaghat Thermal Power Plant	Local Soil
Percentage material passing 75μ Sieve	02	20	65	29
Modified Proctor test Maximum Dry Density (gm/cc)	1.71	1.17	1.33	2.15
Optimum moisture content (%)	12.2	31.0	25.0	9.4
Permeability (cm./ sec)	$3.11x10^{-3}$ -	$6.26x10^{-3}$	$7.2x10^{-4}$	-
Liquid Limit (%)	-	-	-	35.4
Plasticity Index	NP	NP	NP	15.7
Direct Shear Test Cohesion "C" kg/ cm²	0	0	0	0.23
Angle of internal friction (Ø)	32^0	30^0	34^0	25^0

7.4 Fly Ash Use in Road Works

Table -4

S. No.	Name of the Project	Total quantity of No fly ash proposed to be used
1.	km 8-2 to km 29.3 of NH-1in Delhi	100000 Cum
2.	Haldia port connectivity of NH-41 project-4 laning from km 0 to km 52.7	1180000 Cum
3.	km 470 to km 483-33 & km 0 to km 380of NH-2 in U.P.	335000 Cum
4.	4/6 laning of NH-6 in WB from km17.6 to km 72	3234623 Cum
5.	4/6 laning of NH-6 in WB from km 72.0 to km 132.45	321300 Cum
6.	Dungapur Expressway	900000 Cum
7.	Allahabad Bypass on NH-2	6732000 Cum

7.5 Slope Failure of Road Embankment Constructed with Coal Ash

The Noida-Greater Noida Express-highway near Delhi, which is 23 km long, was constructed in a total span of approximately 3 years. It is a six lane express highway with divided carriageway. The height of the embankment on the total stretch is generally 1 to 2 m. However, at certain locations where the alignment crosses an under pass, the height of approach embankment varies from 6 to 8 m. The entire embankment was constructed using fly ash in its core and soil cover was provided along the slope and top portion of the embankment to prevent erosion. Intermediate soil layers were also provided with in the fly ash core. The highway was opened to traffic in the year 2003. In August 2004, after the heavy rainfall in quick succession, it was observed that the side slopes in high embankment portion had severely eroded and gullies were formed throughout the high embankment slope. It was also observed at few spots that due to the piping action, the water had undermined the entire soil cover provided on the side slopes resulting in the exposure of fly ash layers. Detailed investigations were undertaken and causes of failure were identified as follows:

- Severe erosion on the superlevated portion had taken place due to heavy run-off from six-lane carriageway, which was discharged on one side of the embankment.

- Absence of longitudinal kerb channel and chutes allowed water to drain off along the slope.
- Deep pits were made in the embankment slopes to fix utilities like electric poles and crash barriers, which were backfilled with loose soil.
- Run off water entered into the embankment side cover and caused deep cavities exposing fly ash at many locations.

The remedial measures suggested included filling of the cavities with granular material and compaction of side slopes, provision of toe wall, provision of kerb channel and chutes at regular intervals to take away the rain water safely and provision of stone pitching along with filter medium on the side slopes. The repair and restoration of the embankment is under progress.

The proposed road alignment passes through waterlogged area. The water table in the area is very shallow and rises up to or above the ground during the rainy season. The subsoil at site generally consisted of silty clay or clayey soil up to a considerable depth. Such soils settle even under smaller loads imposed due to embankment of low height. However, if a lightweight material like pond ash is used in place of soil, the amount of settlement would certainly reduce.

The results of the stability analysis indicated improvement in factor of safety when fly ash was adopted as fill material. Results of stability analysis are given in table-5 below. Keeping in view the site conditions, availability of materials near the construction site, it was suggested that after dewatering, geotextile wrapped sand or bottom ash layer of 0.5 m thickness be laid as base of the embankment. Pond ash embankment protected with 1.5 m thick soil cover was designed as given in Fig. 3 below. However due to contractual constraints, the embankment was constructed by mixing pond ash and sand in ratio of 85:15 and subgrade was constructed using pond ash and soil in the ratio of 75:25

Table -5

Condition	Fill material	Minimum Factor of Safety
Unsaturated Condition	Soil	1.62
	Pond Ash	1.92
Saturated Condition	Soil	1.36
	Pond Ash	1.50

8.0 COLLAPSE BEHAVIOUR OF COAL ASH

8.1 Sri A.Trivedi & V.K.Sud in their paper "Collapse behaviour of coal ash" published in Journal of Geotechnical and Geo-environmental studied Engineering ASCE/April-2004 described an investigation carried out to examine the factors influencing the collapse settlement of the compacted coal ash due to wetting. The brief detail of their paper are given below:

The soils that exhibit collapse have an open type of structure with a high void ratio as expected in the case of ashes. According to Barden et al. (1969) the collapse mechanism is controlled by three factors; (1) a potentially unstable structure, such as flocculent type associated with soils; (2) a high applied pressure which further

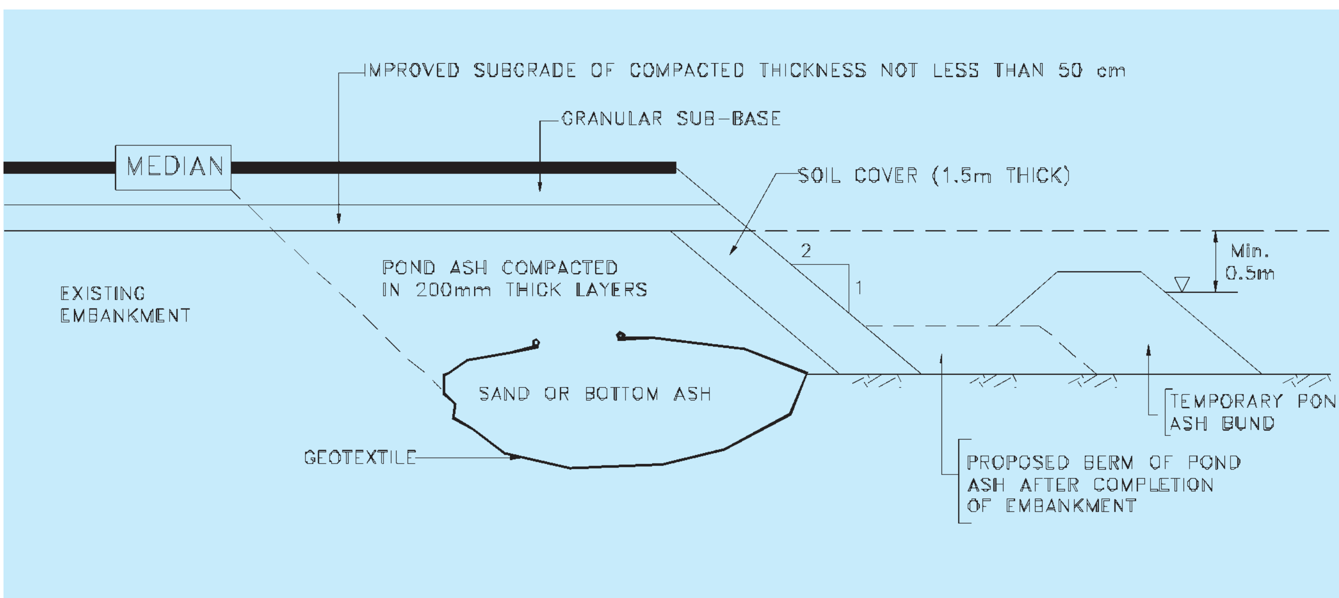

Fig. 3 : Embankment section proposed In NH-6 project

increases the instability; and (3) a high suction which provides the structure with only temporary strength which dissipates on wetting. As per an empirical study by Meckechnie (1989), the dry unit weight and water content are generally considered as important parameters that control the collapse of metastable structure of soils, if the dry unit weight is less than 16 kN m^{-3}. The tentative dry unit weight of the coal ashes in Ropar ash pond was often found to be less than 10 kN m^{-3} suggesting possibility of collapse.

8.2 The collapse potential obtained by the oedometer test is a dependent parameter of several factors such as grain size characteristics, stress level, testing technique, degree of compaction, a finite consolidation ratio, moisture content, soluble substance, etc.

At prewetting critical moisture content and in the critical stress range (50-125 kpa), the ashes tend to collapse more than those in the dry condition. The observed collapse potential was proportional to the collapsibility factor identified from the maximum and minimum void state of the ashes. The ashes with more than 50% of the particles in silt size range were found to be collapsible.

The dry disposed ashes were more collapsible due to the presence of soluble substances as compared to that obtained by the wet disposal. Therefore, a correction was applied in the observed collapse potential of the dry disposed ashes to obtain a common correlation with the mean size as of the wet disposed ashes.

The generally recognized lower limit of collapse potential for the collapsible soils in the oedometer is 0.01. It was observed that the coal ash with a collapse potential of 0.0075 at 80% degree of compaction (Dc) collapsed in model tests at 87% and 94% Dc. Increasing the density of this ash arrested the collapse in the model test. The coal ash with a lower collapse potential (0.0037 at 80% Dc) did not collapse at all while an ash with a higher collapse potential (0.021 at 80% Dc) collapsed at all the densities examined in the model test. Therefore, the lower limit of collapse potential of the collapsible ashes was recommended as 0.0075 at 80% degree of compaction in the oedometer.

In field, the collapse may occur due to the accidental wetting or a rise of water table. In such cases, the magnitude of measured collapse is a function of the depth of wetting front from the ground level. If the wetting front ratio is more than 1.8, a threat of collapse is bare minimum. The field collapse test is recommended under an actual condition of wetting, if ashes are to be used as a structural fill.

9.0 CONSTRUCTION OF RAILWAY EMBANKMENT WITH FLY ASH

9.1 Tamluk-Digha Rail Link

Railway used fly ash from Kolaghat thermal Power plant in Tamluk-Digha new rail link project from ch.10.92 to ch. 12.28 in about 1.30 km in length. This location is situated near Haldi bridge where embankment had failed twice during construction. Fly ash was also used in a near-by location on Panskura-Haldia section between ch.(-600) to ch.775. Section adopted for embankment construction is given below:

RDSO officials visited Tamluk–Digha section of South Eastern Railway along with railway officials for performance appraisal of fly ash embankment in July 2005. This section opened for traffic on 20.11.2003. Main observations of visit are as under:

- The axle load of the section is 17 tons and GMT 0.22.
- The sectional speed is 80 kmph and speed restriction of 30 kmph is imposed between km 12/0 to km 13/3 where fly ash was used due to erosion.
- The track attention near Haldi bridge location was reported as 2 per month.
- The variation in cross level is reported as 4.0 mm to 8.0 mm.
- Erosion of side slope occurred due to removal of side cover of fly ash embankment on account of movement of cattle or any other reason. The large

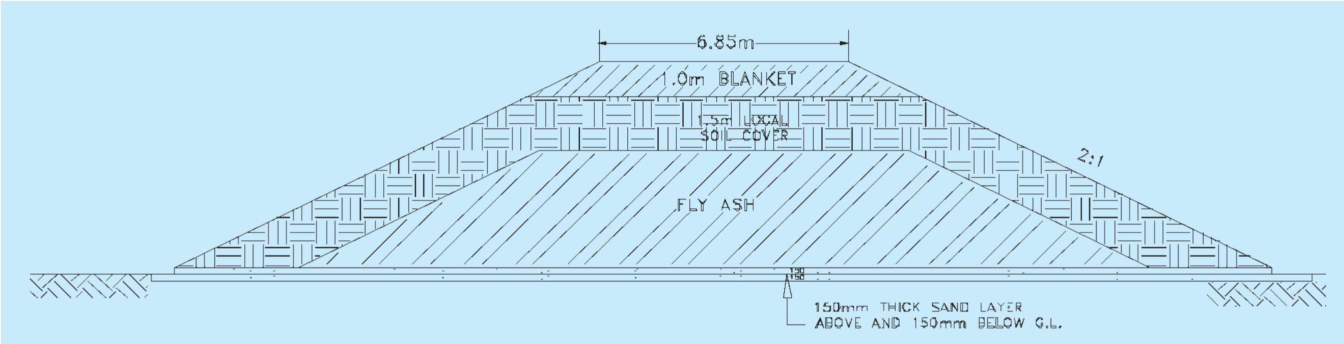

Fig. 4 : Location : Ch. 12.005 near Haldia river towards Tamluk end

amount of fly ash had eroded and settlement occurred between hume pipe bridge no. 24 and 25 in December 2004.

9.2 NTPC Hurra Connection at NTPC Kahalgaon MGR, Bihar For bulk utilization of coal ash , National Thermal Power Corporation (NTPC) took an initiative and formed a team comprising of officials from Central Road Research Institute (CRRI), New Delhi, Indian Institute of Technology (IIT), Mumbai and Research Designs and Standards Organization (RDSO), Lucknow. This team was requested to assist NTPC in taking up a pilot project on 'Design and Construction of Coal ash Railway embankment.' It was decided on mutual interactions that, CRRI would develop different technical cross sections of the railway embankment. After that, IIT Mumbai would evaluate these cross sections by centrifuge model studies, and RDSO would give their regular inputs for finalization of designs/guidelines for construction of coal ash railway embankment. Based on these designs, NTPC would carry out construction of coal ash railway embankment at Hurra connection at NTPC Kahalgaon MGR, Bihar. It was decided that based on the data generated from the pilot project, guidelines needs to be formulated for utilization of coal ash for large scale field applications. The team from NTPC would coordinate the entire project activity.

9.3 Japanese Safe Siding at Nagasaki Main Line

Japanese railway use coal ash for construction of railway embankment on a safe siding of Nagasaki main line. In this case, levee widening was done using coal ash so that safe siding could be laid on the existing embankment, which stood on weak ground with a top layer having an N-value of about 2 by standard penetration test which extended 4-5m. Ground subsidence was expected to occur as a result of levee widening. To prevent this, the ground improvement had to be done or a technology of light weight embankment construction had to be adopted. Besides, with land demarcation coming close to the foot of the embankment, the slope had to be designed vertical to secure the necessary formation level width. For these reasons, coal ash was taken as the material which would give a high strength embankment; it is about 30% lighter than the common soil and when reinforced with a net (geogrid) it enables construction of vertical slope.

10.0 CONCLUSION

It can be seen that so far very limited length of railway embankment has been constructed using fly ash. The lines constructed so far are either branch line having very less traffic or limited length good siding. Railway embankment is quite different from road embankment due to the fact that the railway embankment is pervious compare to road embankment. The water can easily reach the core i.e. fly ash. OHE foundation and other foundation laid over the top of embankment also make the embankment pervious. The railway embankment is designed for very tight safety tolerance. The study reveals that fly ash is highly erodible in nature, railway embankment run through very remote places where the protection of side cover cannot be maintained. Therefore, coal ash cannot be used directly in railway embankment. The collapsibility nature of fly ash (low dry density) needs more experimentation and field validation. To overcome these problems, construction of embankment with fly ash requires specialized method wherein fly ash has to be used in combination with naturally occurring soil. Extensive monitoring of field performance of embankment constructed with fly ash on an experimental basis is required before usage of fly ash could be propagated on wider scale.

REFERENCES

1. Use of Coal Ash in Embankment Stability Analysis and Design Consideration by Sri Manoj Dutta.
2. Engineering properties of Coal Ash by Sri Manoj Dutta .
3 Collapse behaviour of coal ash by Sri A.Trivedi & Sri V.K.Sud.
4. Construction of Road embankment and reinforced earth wall using fly ash by Dr. Sudhir Mathur and others.
5. Fly ash in road & embankment by Dr. Vimal Kumar and others.
6. Engineered Fills by Thomas Telford.

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