

# RAINBOW FOOT OVER BRIDGE COLLAPSE AT JNS (2010)

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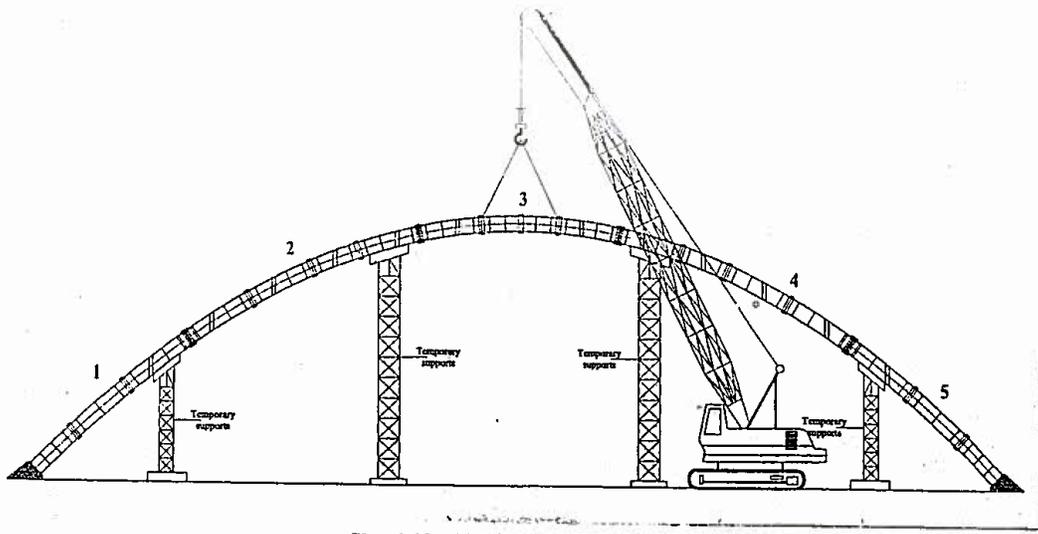


**Photo no. 1:- Showing completed Structure of FOB.**

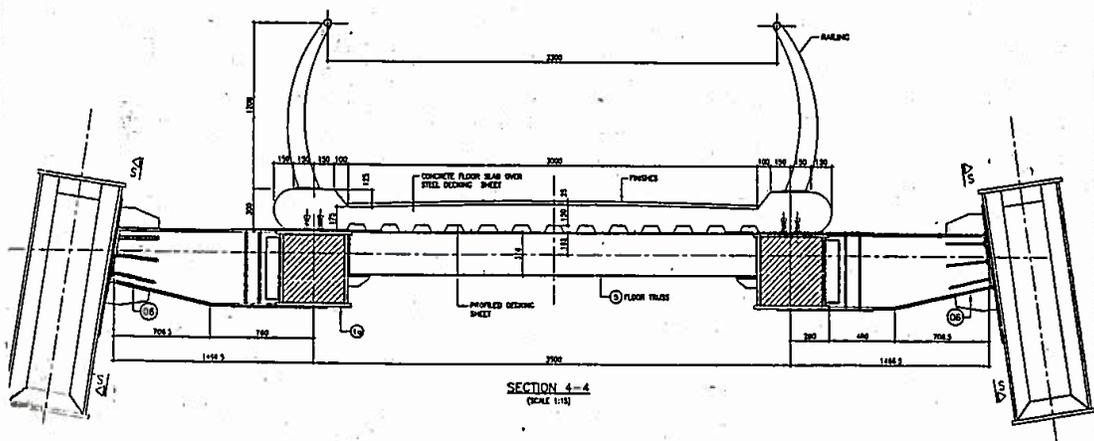
## **1. Synopsis:-**

This article is about the Foot Over Bridge, the deck of which collapsed on 21<sup>st</sup> September 2010, while laying concrete of the deck slab.

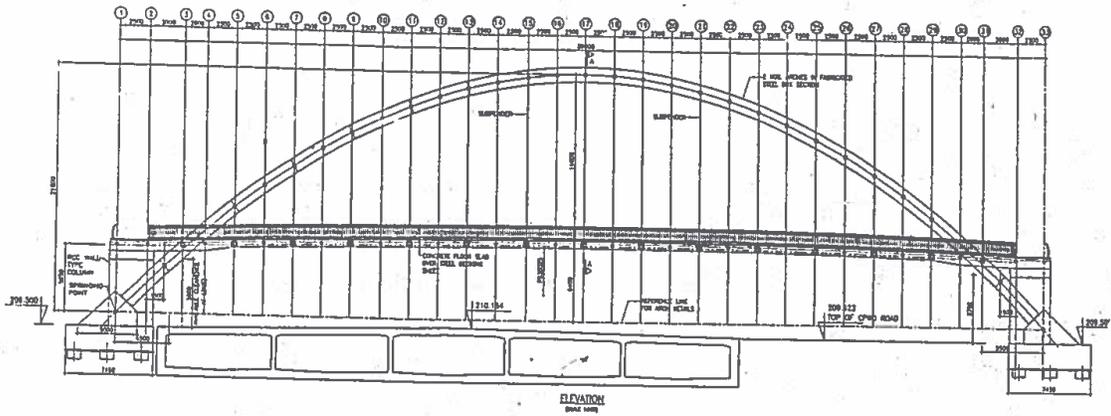
|   |  |
|---|--|
| Other Names   | Common Wealth Games Suspension<br>Foot Bridge/ Rainbow Bridge  |
| Design  | Incorporating paired steel arches to<br>hang deck slab by use of 26 Macalloy<br>stainless steel suspenders of 36 mm dia. |
| Total length  | 80.0 m   |
| Clearance below   | 5.70 m   |
| Construction started  | April,2010   |
| Scheduled date of completion  | Sept 30, 2010, 95% work completed  |
| Deck collapsed due to failure of suspender connections on               | Sept 21,2010   |
| Actual date of completion after use of modified design of<br>suspenders | February, 2013   |



Sketch No. 1(a) Showing Erection Methodology



Sketch no. 1(b) Showing elevation of bridge



Sketch no. 1(c): Showing transverse Section of bridge

The footover bridge was meant to connect the Games Venue of Jawaharlal Nehru Stadium to a “park and ride” lot at Safdarjung Airport and was meant for use of over 10000 spectators and athletes per day. It was to give direct access to the venue, overcrossing the busy highway, and a parking lot at JLN Stadium. Two FOBs were planned to add beauty to the supporting event and have spectacular distinct landmark features of rainbow shaped paired arches supporting a steel-concrete composite deck hung by Macalloy suspenders imported from United Kingdom. The design and drawings of the FOB were got prepared by Delhi PWD from Consultants and duly proof-checked and approved by the Central Road Research Institute (CRRI) before issue to M/s P&R Infraprojects Ltd the contractor to whom the work of preparation of shop drawings, fabrication and erection was awarded. The fabrication drawings prepared by the contractor were approved by Delhi CPWD after vetting by the Consultants.

The work was awarded in the month of March 2010 to be completed within six months i.e. by end September 2010. However the execution was substantially delayed due to reasons such as:-

- Delay in receipt of concept drawings.
- Delay due to modifications in drawings.
- Delay due to change of M.S. bars to Macalloy bars for anchor bolts.
- Delay due to change of Macalloy GI to SS suspenders.
- Delay due to shipment of suspenders on account of oil spillage in Mumbai harbour.
- Delay due to exceptionally inclement weather created by prolonged rainy season.

The contractor submitted the fabrication and erection methodology of the paired arches and erected the arches successfully on piled foundations as shown in SKETCH No. 1. The suspenders were installed as per the instruction manual of Mac-alloy, being bought out items. The contractor, accordingly installed the suspenders as per approved drawings to hang the steel pre-fabricated deck structure for both the FOBs. However when the concreting of the one FOB was being laid and about 45 m of deck length was poured the deck fell down with a thunderous sound injuring 27 workers, some seriously, breaking itself in three parts, though no life was lost (Photo No.2).

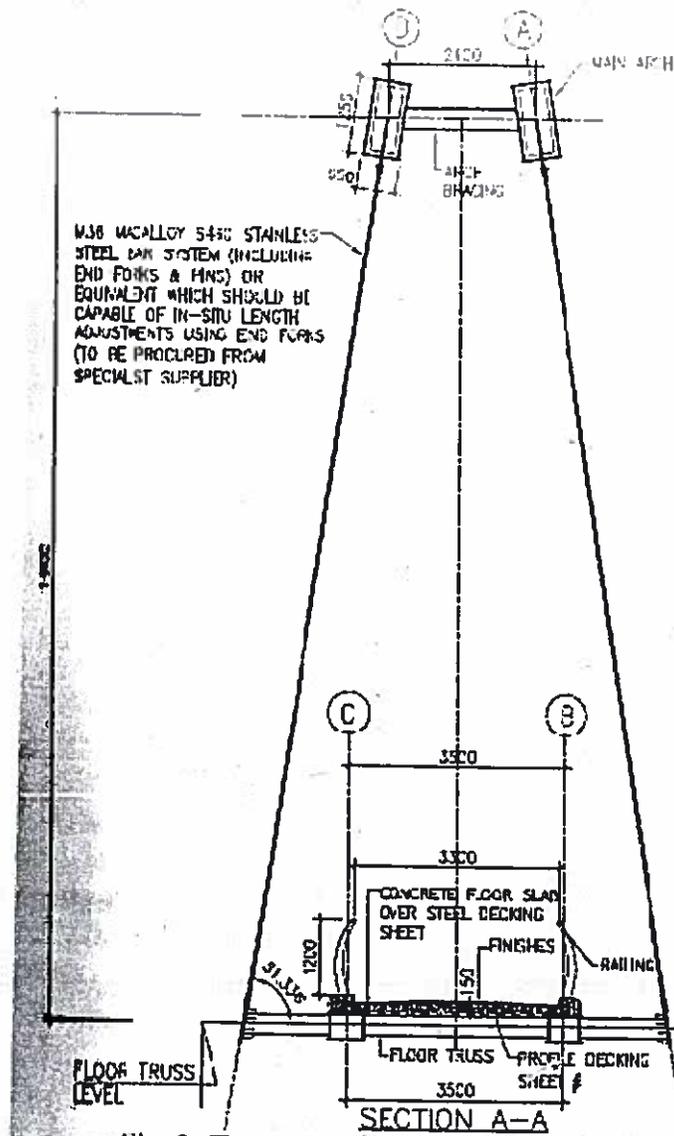


**Photo no. 2:- Showing Collapsed deck of FOB**

## **2. Design and Construction**

The remarkable design of FOB was conceived by M/s TCPL and approved by Delhi PWD. TCPL proposed paired-arches of fabricated steel box section of size 1250 mm x 650 mm, span 80m, rise 14.6 m, braced with pipes of 350 mm dia, splayed at supports by 8.80m from 3.40m at the crown. The deck of span 80 m, width 3.50 m was having fabricated steel boxes of max. size 550 mm x 550 mm at c/c distance of 3.5m braced by square box sections to supports a 150 mm thick RCC deck slab. The deck was proposed to be hung by twenty six Macalloy S -460 stainless steel suspenders of diameter 36 mm at 5 m c/c. The maximum length of suspender being 14.6 m and maximum inclination from vertical of 9 degrees. The suspenders were tied at bottom centre of the arches at top and to a cantilevered plate connection on both sides at deck level, SKETCH No. 2.

The contractor fabricated the sections of the arches and deck structure at his approved workshop, with specified materials and methodology, which were dispatched to work site after proper testing and checking. The arches were erected as per methodology submitted by the contractor by installing temporary towers as shown in SKETCH No. 1(a). The specified Macalloy suspenders, procured by the contractor, were hung as per approved drawings and the deck sections were erected. After approval of the completed steel structure the contractor under took laying of ready mix concrete, procured from an approved source, so as to complete the entire work of both FOBs by end September 2010, when the deck of the first FOB got detached from suspenders, and fell on ground on September, 21, 2010.



SKETCH No. 2: Transverse Sectional Elevation at Crown of Arch

### 3. Possible causes of failure of bridges

As per recent international studies it has been established that major bridges keep on failing and collapsing, around the globe, with a frequency of 30 years, causing loss of life and humiliation to the engineers due to the three main reasons, out of the all possible reasons, as enumerated in TABLE No. I, namely:-

Design deficiencies

Construction errors

Force- majeure, natural phenomena and extreme events

Records also show that fifty percent of failures are attributed to design deficiencies and Twenty Five Percent each to construction errors and natural causes, respectively.

**TABLE –I**

**POSSIBLE CAUSES OF FAILURE OF BRIDGES**

**Source:- Bridge and Highway Structure Rehabilitation and Repair by Mohiddina Khan**

| <b>Design deficiencies<br/>(failures 50% to 55%)</b>  | <b>Construction errors<br/>(failures 20% to 25%)</b>                                   | <b>Force majeure reasons<br/>(failure 20% to 25%)</b>                                       |
|---|--|---|
| <ul style="list-style-type: none"><li>• Inaccurate design assumptions</li></ul>   | <ul style="list-style-type: none"><li>• Erection errors</li></ul>                      | <ul style="list-style-type: none"><li>• Flood and scour failures</li></ul>                  |
| <ul style="list-style-type: none"><li>• Inability to define loads accurately</li></ul>  | <ul style="list-style-type: none"><li>• False work failures</li></ul>                  | <ul style="list-style-type: none"><li>• Unpredicted excessive wind velocity</li></ul>       |
| <ul style="list-style-type: none"><li>• Limited redundancy in structural system</li></ul>   | <ul style="list-style-type: none"><li>• Use of defective materials</li></ul>           | <ul style="list-style-type: none"><li>• Earthquake</li></ul>                                |
| <ul style="list-style-type: none"><li>• Lack of information of new materials</li></ul>  | <ul style="list-style-type: none"><li>• Un-suitable temporary works</li></ul>          | <ul style="list-style-type: none"><li>• Fire</li></ul>                                      |
| <ul style="list-style-type: none"><li>• Complex behaviour of structure</li></ul>  | <ul style="list-style-type: none"><li>• Joint and connection failures</li></ul>        | <ul style="list-style-type: none"><li>• Barge/ship impact</li></ul>                         |
| <ul style="list-style-type: none"><li>• <b>Inelastic behaviour of connections</b></li></ul>                                       | <ul style="list-style-type: none"><li>• Strong winds and hurricanes</li></ul>          | <ul style="list-style-type: none"><li>• Fatigue</li></ul>                                   |
| <ul style="list-style-type: none"><li>• Bearings, Joints, splices, gusset plates, bolts and welds not properly designed</li></ul> | <ul style="list-style-type: none"><li>• Improper sequence of erection</li></ul>        | <ul style="list-style-type: none"><li>• Brittle fracture</li></ul>                          |
| <ul style="list-style-type: none"><li>• Inadequate access to bearings</li></ul>   | <ul style="list-style-type: none"><li>• Improper sequence of concreting</li></ul>      | <ul style="list-style-type: none"><li>• Corrosion</li></ul>                                 |
| <ul style="list-style-type: none"><li>• Indifferent behaviour of soils</li></ul>  | <ul style="list-style-type: none"><li>• Improper placing of reinforcing bars</li></ul> | <ul style="list-style-type: none"><li>• Sabotage</li></ul>                                  |
| <ul style="list-style-type: none"><li>• Inability to predict behaviour of different soils behind abutments</li></ul>              | <ul style="list-style-type: none"><li>• Incorrect prestressing</li></ul>               | <ul style="list-style-type: none"><li>• Old age and Inherent defects</li></ul>              |
| <ul style="list-style-type: none"><li>• Lack of drainage</li></ul>  | <ul style="list-style-type: none"><li>• Incorrect thickness of gusset plates</li></ul> | <ul style="list-style-type: none"><li>• High temperature differences</li></ul>              |
| <ul style="list-style-type: none"><li>• <b>Detailing errors</b></li></ul>   | <ul style="list-style-type: none"><li>• Welding deficiencies in connections</li></ul>  | <ul style="list-style-type: none"><li>• Overloading</li></ul>                               |
| <ul style="list-style-type: none"><li>• Aerodynamic instability</li></ul>   | <ul style="list-style-type: none"><li>• Loose bolts and loose rivets</li></ul>         | <ul style="list-style-type: none"><li>• Impact by braking of trains</li></ul>               |
| <ul style="list-style-type: none"><li>• Inadequate bracing</li></ul>  | <ul style="list-style-type: none"><li>• Inexperienced contractor</li></ul>             | <ul style="list-style-type: none"><li>• Blasts</li></ul>                                    |
| <ul style="list-style-type: none"><li>• <b>Non-provision of Construction and Erection methodology by Designers.</b></li></ul>     | <ul style="list-style-type: none"><li>• Inexperienced workers</li></ul>                | <ul style="list-style-type: none"><li>• Gradual reduction in strength of concrete</li></ul> |
| <ul style="list-style-type: none"><li>• In-experienced designers, detailors and proof checkers</li></ul>                          | <ul style="list-style-type: none"><li>• Rush working-Lack of QA checks.</li></ul>      | <ul style="list-style-type: none"><li>• Inadequate maintenance measures</li></ul>           |

**NB: Bold reasons were the main villains of collapse of Delhi FOB**

#### **4. Enquiry committees for collapse of FOB**

Immediate on collapse of the FOB the NCR-Delhi Government constituted two committees to enquire into the causes of the failure, to pin point the responsibilities and to suggest measures to avoid recurrence of such incidences as under:-

|  |   |
|--|---|
| • Technical Investigations (Dogra committee) | Comprising of Er. HM Dogra ex. DG of CPWD and Dr. Ashok Gupta of IIT Delhi  |
| • Forensic Investigations                    | The Delhi Police crime branch appointed IIT Roorkee to conduct forensic investigation who detailed Dr. Bhupender Singh and Dr. Vipul Parkash to deal with the case. |

Of their own the contractors, M/s P&R Infraprojects Ltd, appointed the following three independent and reputed agencies to conduct the technical investigations of failure:-

- PRABHU STRUCTURALS  
Consultant & Engineers – N. Delhi
- Futura Design Consultants Pvt. Ltd. – Ludhiana
- Kiri Associates Pvt. LTd. Consultants, Architects, Engineers & Builders – N. Delhi

All the three above agencies are well experienced in conceptualization of shapes, designing, drawings, construction and supervision of all types of steel and concrete bridges including suspension bridges and FOBs.

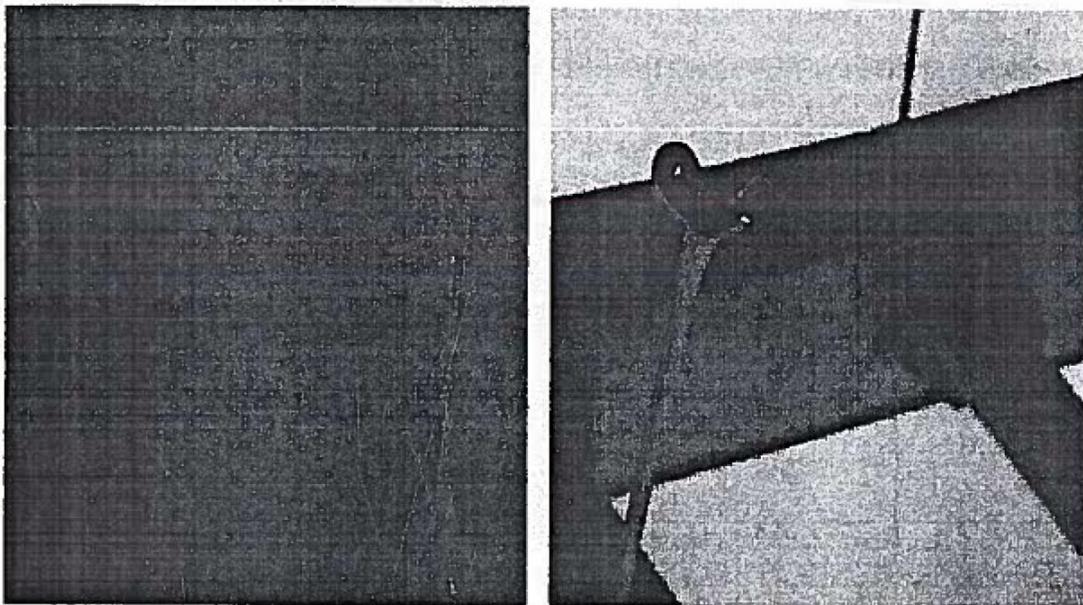
All enquiry committees visited the site of the accident, collected samples of materials, took photographs, took statements of the representatives of the TCPL, PWD engineers, contractors representatives and workers and also collected copies of the relevant documents in regard to design, drawings, MTRS, construction methodology, QA reports etc. etc. as deemed necessary for in depth study of the case.

#### 4.1 Reports of Enquiry committees and private consultants.

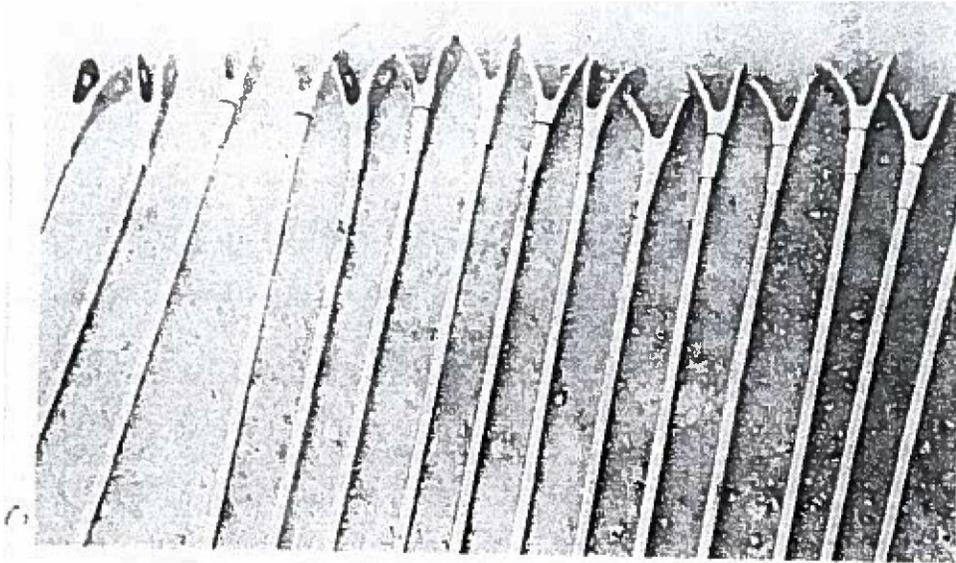
Firstly the contractor received the technical reports of the three independent Consultants appointed by him which were forwarded to the two committees appointed by the Delhi PWD. These Consultants reported the following causes of the collapse:-

- **Brief of Report of PRABHU STRUCTURALS:-**

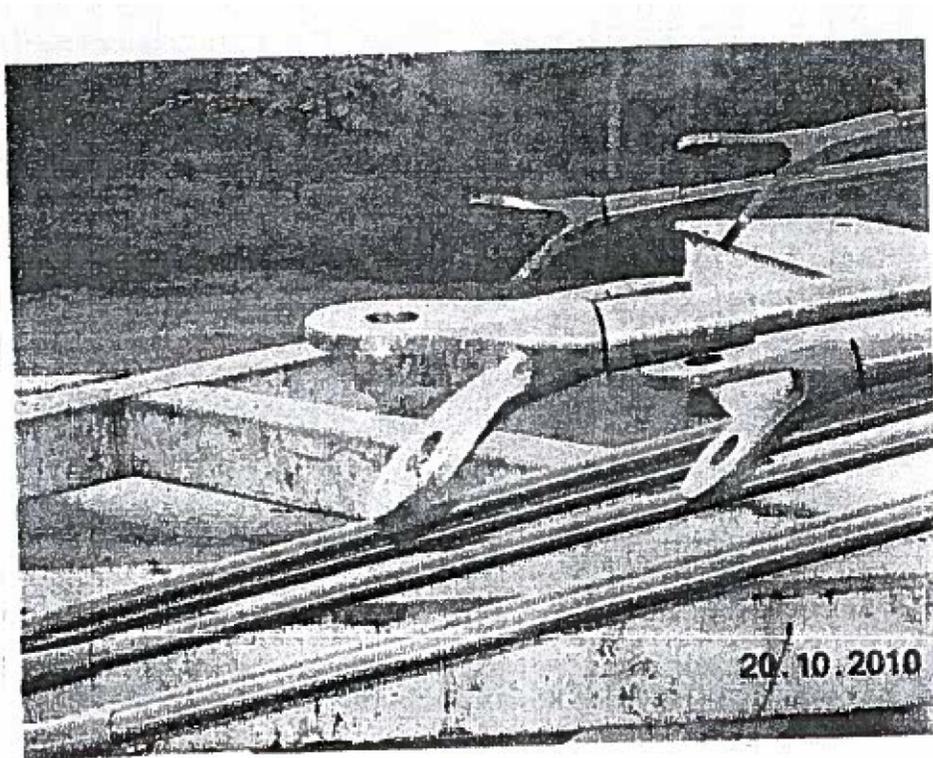
1. It is obvious that the suspension fork and pin have given way because the pin has been detailed by the designer perpendicular to the axis of the bridge which restricted the movement of the suspender around the pin to cater to the changing deflection caused by the loading. The eye lets of the fork opened out due to inadequate fastening/ locking of the pin because of uncatered load/ moment as shown in photos no. 3 (a), (b) & (c).



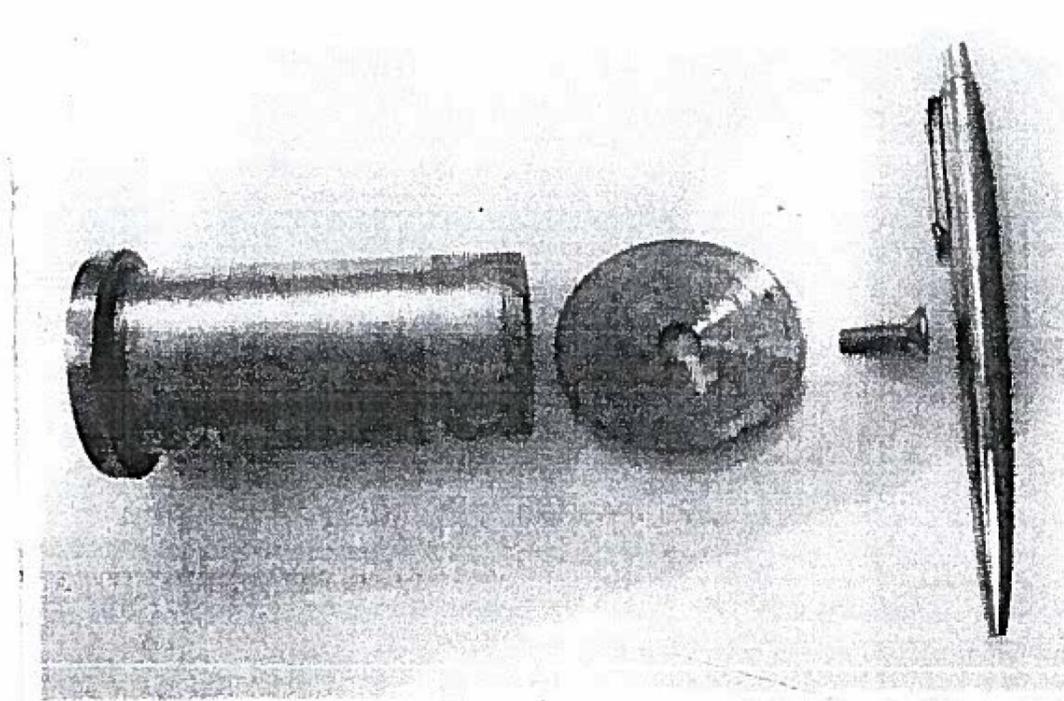
Photos no. 3(a) & (b): View of the fork type connector at suspender ends after collapse of FOB -2



**Photo no. 3(c): Bending of the arm of the fork type connector was seen in almost all the suspender rods retrieved from the site.**



**Photo No. 4: Close up view of a fork-type connector retrieved from the collapsed bridge.**



**Photo No. 5: Exploded view (L–R) of a shear pin with an end-retainer plate attached at its left end, end retainer plate and a retainer screw. A pen is placed next to these components for purpose of comparison with respect to sizes of the different components.**

2. To provide a welded cleat connection of ISAs to the box girder, in the cantilever portion to hang the suspenders, with fillet welds at 144 mm distance, as shown in SKETCH No. 2 is a very wrong idea which was subjected to bending moment over and above the shear force. The welds were subjected to heavy impact load when the bridge fell and hit the ground damaging connections

On the whole the bridge collapsed on account of the above said points and express the want of correct designing of the details of the joints whether it is a suspension or a girder bridge

#### **4.2 Report of Futura Design Consultants Pvt. Ltd.:-**

The following design inadequacies were observed in the FOB of JNL Stadium:-

##### **1. Restriction to Thermal Expansion/ Moment:-**

There is no scope for movement due to thermal expansion/ contraction at support locations. The deck should be provided with bearings at location of crossing of the arch or at the ends where it is supported on columns or both locations. However it has been bolted at columns locations, which has arrested the scope of movement & builds stresses in the structure, which are avoidable. On the contrary, the deck has been welded to the arch and its movement therefore is restrained, which is very unusual for particularly long span bridge, where the movement from centre will be of the order of 40 mm (+20/-20mm) on either side.

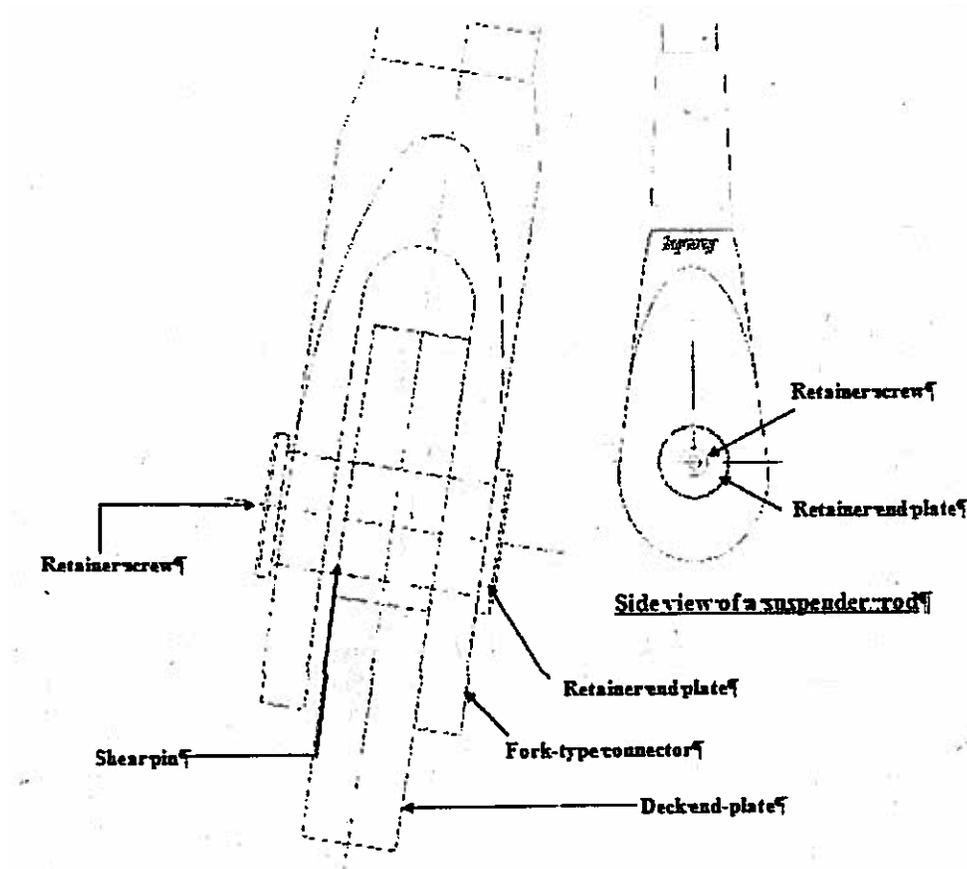
##### **2. Rigidity vs flexibility**

The arrangement of deck provided i.e. suspended with hangers is essentially a flexible structure, has been contradicted by detailing. Providing a very rigid deck truss and restraining its movement at ends at arch & deck made by providing forks in perpendicular direction it rigid structure, the detailing does not leave any scope for rotation at ends in transverse direction, the basic purpose of provision of fork end arrangement at hanger ends both at arch & deck is defeated. The deck grid structure has been made very rigid.

##### **3. Fork connection**

The incorrect fork arrangement provided with the pin in the transverse direction of the deck (T-T axis) has restricted the transverse rotation of the deck, while the pin should be provided in the longitudinal direction, SKETCH No. 3 & 4. It has lead to loading of the fork arm for which the product is not designed for. It has

caused failure/ bending of the fork arm, hence the pin and thus the bridge. It is clear from the failure pattern of different hangers shown in photo 3 & 4.



**SKETCH NO. 3: Typical arrangement of a fork-type connector and names of its parts.**

#### **4. Hangers/Suspenders**

Hangers have not been designed for accidental snapping of one of the hangers or provision for replacement during damage to any of the hangers has not been made as provided for another similar bridges.

#### **5. Connection to bracket**

The deck has been connected to hangers through a cantilever bracket which has been attached with a plate at the end, which is not a robust connection, the transverse beam/ cross girder should be a single beam & longitudinal beams/ stringers provided in between, which will be a dependable arrangement, SKETCH No. 2.



2. As per design calculations of TCPL the suspenders are subjected to a maximum load of 14.6 Tonne in worst scenario. The suspenders being hung at an angle of 9 degrees to the vertical could have generated a horizontal force of 2.284 tonne on the fork legs when subjected to this load. This horizontal force is transmitted to the screw M – 6 (4.5mm nominal rod diameter) and a Bending moment in the fork for which these were not designed. The Retainer screws M-6 have a rated Tensile Breaking strength of 0.667 Tonne and will fail at appreciably less than the 2.284 Tonne load that they could be subjected to at the Maximum Loading. Accordingly after Tensile failure of the retainer screws, the two legs of the fork type connectors got splayed and became independent of each other, and Bending Moment caused one or both the legs to bend outwards and disengage from the shear pin, resulting in total lack of support for the Deck structure as show in Photo No. 3.
3. During observation at site no defect in materials used and workmanship could be found.
4. There is no doubt whatsoever about the fact that the failure occurred primarily due to ignorance, inexperience and gross negligence on the part of the Designers and the Approving Authority.

#### **4.3.1 Report of Dogra Committee appointed by Delhi – PWD (As per PTI release)**

The panel, set up to probe the collapse of the foot over bridge near JN Stadium just before the Commonwealth Games, has blamed PWD for “supervisory failures” while it held P&R Infraprojects Ltd for carrying out the project in a great hurry as reported in a newspaper release:-

According to the official release, the panel has pointed out that the design consultant M/s TCPL did not give the methodology of construction and the contractor devised the procedure on its own without taking any necessary approval. Sources said that since the project had to be completed within one week, the contractor did not submit any construction methodology and it never came up for approval. PWD officials said that the contractor was not a ‘novice’ since it had executed major projects by then.

The release said, “As per the report, the cause of the collapse could be asymmetrical loading more than permissible level which resulted into over-stressing of Macalloy joint connecting the deck slab with the Macalloy suspenders that were imported from UK. The committee also brought out that while fabricating the deck, a slightly thicker gusset plate was used due to non availability of the recommended size. “We had little time, so we went for slightly thicker gusset plates. But those were manufactured by the best companies,” a senior PWD official said.

The report said that UK firm M/s Macalloy which supplied the suspenders had said after the incident that it felt “the orientation of the gusset plate was in the wrong plane.” However, no such observations were made by them when the

drawings were forwarded to them in April 2010 by the contractor for fabrication of the system. When asked by the probe committee to clarify why this suggestion was not given in April 2010, M/s Macalloy have not provided any response, government said.

NONE TO BLAME: PWD official said that the contractor was not a 'novice' since it had executed many other major projects.

#### **44.1 Report of Forensic Investigation Team**

The Delhi Police crime branch was assigned to conduct forensic investigations in association with IIT Roorkee in regard to the general and standard aspects of:-

- Expert interviews of witnesses.
- Checking technical aspects like knowledge, experience and competency of consultant, contractor and client.
- Use of detective skills to check the quality of materials used, tampering of samples, authenticity of records, sabotage, mischief, pilferage, hiding and altering records etc.
- Legal aspects of the damage caused.
- Work place safety and liability.
- Compliance with codes.
- Corruptive practices.
- Causes of failure as the primary objective

The Police Department did not find any of the above defects but came to a unsubstantiated conclusion that the collapse occurred due to lack of supervision and hasty execution of works. The injured persons were suitably compensated as per directions of the Honble Court by the contractor.

#### **4.4.2 Report of Collapse of the Foot Bridge by Department of Civil Engineering IIT – Roorkee:-**

As a consequence of detailed examination of the fallen bridge structure, design calculations, proof checking, construction methodology adopted, the quality of materials used, quality assurance systems observed and work site supervision aspects the IIT Roorkee submitted its report with the following predominant and important observation:-

#### **(a) The IIT Roorkee observed the following nine deficiencies in design of the bridge:-**

**DEFICIENCY : 1**

It is not understood why the suspenders are provided at a longitudinal c/c spacing of 5.0 m i.e. at locations of alternate X-girders, rather than at 2.5 m intervals, i.e. at the locations at which the X-girders have been provided both in the arch and in the lateral steel floor truss carrying the RCC deck slab.

**DEFICIENCY : 2**

It is not understood why the suspenders had to be stainless steel bars, M36 Macalloy S460 Stainless steel bar system (including and forks & pins) or equivalent and capable of in-situ length adjustments using end-forks to be procured from specialist supplier.

**DEFICIENCY : 3**

It is not understood why the structural designer did not choose to shorten the gravity load path and make it more robust.

**DEFICIENCY : 4**

It is not understood why the structural designer chose to provide the cantilever brackets.

**DEFICIENCY : 5**

The x-section of the cantilever bracket and the X-girder between the L-girders are sized disproportionately to the design requirement.

**DEFICIENCY : 6**

The X-girders between the L-girders are considered as hinged at their connections with L-girder in STAAD computer analysis.

**DEFICIENCY : 7:**

The site splice detail between arch segments appears to be incapable of transmitting bending moments from one segment to the other, except small amount due to friction and pre-tension of the bolts.

**DEFICIENCY : 8**

The 8 mm thick chequered plate is too thick from any design considerations or from considerations of good engineering practice.

**DEFICIENCY : 9**

It is nor understood that when steps and landings in the staircases leading to the bridge could be in steel, why a similar steel deck not deemed suitable for the bridge. What was the necessity of providing a much heavier 150 mm thick RCC deck slab.

**(b) Based upon the impact of the nine design deficiencies and the mode of failure taken place during collapse of the bridge the IIT Roorkee gave the Conclusion as under:-**

**Conclusion by IIT Roorkee:-**

Nine critical deficiencies in the structural design were identified, reasons for considering them as deficiencies were provided, and better design alternatives were also suggested. This way of presentation was chosen to facilitate the structural designer in providing the needed clarifications to dispel there deficiencies.

Without the needed clarifications, it can be concluded that all these deficiencies arose owing to short-circuiting of the structural design process by the designer of the bridge, who chose to omit the preliminary analysis and design phase. Owing to this omission, the designer failed to visualize the gravity and lateral load paths for this structure. Consequently computer analyses was carried out based on wrong design decisions, reflected in Deficiencies 1, 3, 4, 5, 6 and 9, which became the basis for an uneconomic and unsafe design. Deficiencies 2 and 8 especially show that the designers were not sensitive towards achieving an economical design outcome.

Preliminary analysis and design was to be carried out manually and members and their connections were to be designed in the sequence dictated by the load paths, which are shown in (SKETCH – 4) for this bridge. This preliminary analysis and design document was to be submitted along with computer analysis and design notes and drawings for proof checking the design. Only then proof-checking could and should have been ideally carried out.

The preliminary analysis and design document could and should also have been checked by the government department entrusted with the task of getting a public facility constructed, so as to ensure an economical and safe structure. This checking would also have equipped the government department with the understanding needed to supervise the construction of the bridge with the needed quality control at the site. This checking would also have enabled the government department with the understanding needed to maintain the structure during its service life.

These deficiencies resulted in an unsafe as-well-as an uneconomical bridge, which collapsed while it was being constructed.

Owing to deficiencies 1 and 9, the bridge was especially vulnerable to progressive collapse on failure of a single suspender, which could have occurred at any time during the service life of the bridge.

The post collapse evidence was reviewed. It was concluded that a progressive collapse occurred due to the failure of “Architectural” components in the fork-type connectors at the ends of suspenders Photo – 3. This progressive collapse of the bridge was aided by the heavy RCC deck slab (Deficiency 9), and the larger suspender spacing chosen by its designers (Deficiency 1).

The unwarranted choice of the Macalloy stainless steel bars as suspenders is specified in the General Arrangement Drawing (Deficiency 2). As per product technical approval document available on Macalloy’s internet website, the chosen product was suitable only for predominantly static loads, and not for sudden or impact loads, nor for systematic bending. Further, the product needed to be accessible in order to facilitate replacement of individual components at any time.

The above conclusion almost matches with the findings of the other Consultants and Committees as narrated above.

**(c) As regards review of the Construction aspects the IIT Roorkee opined as under:-**

The arches were to be erected in a total of five segments and the erection methodology proposed by the contractor of the bridge was found to be satisfactory. A perusal of site records made available to the technical team indicates that a reasonable quality control system related to the various construction activities was in place at site. As part of quality control, regular third party testing of steel, paint and welding consumables has been carried out during the course of the bridge construction and the material test reports indicate compliance with specifications and have been seen to be compiled in a proper manner and are available for ready inspection. It is noted that the paints have been sourced from a reputed manufacturer like AkzoNobel and welding consumables were of Esab make, another reputed supplier. The test reports show that the medium and high strength micro alloyed structural steel was sourced from Steel Authority India Ltd. a known manufacturer of such material. TATA steel supplied the hot rolled coils for the bridge. The test results of the high yield strength steel reinforcement bars of 16 mm and 20 mm diameter indicate compliance with requirements of IS: 1786-2008.

Records of site inspection reports related to Fit-up, welding and painting processes during fabrication of the arch segments and the deck have been maintained at site and upon review were found to be satisfactory. The ultrasonic test reports made available to the technical team do not indicate any distress in the welded joints or the steel plates which were subjected to testing in the bridge structure.

A review of the quality management in the construction of the FOB – 2 indicates that the quality assurance and the quality control techniques were reasonably commensurate with the scale of the project though greater involvement of site representatives of the client in the quality management would have been desirable. A majority of the quality control reports indicate the complete absence of first party, i.e. the client. Therefore, there is no independent check on the activities of the second party, i.e. the contractor, and the third party i.e. the testing agency in the quality control process.

#### **5. Macalloy SS Suspenders S – 460:-**

- Macalloy Prefabricated Tension Rod System. The European Technical Approval for the stainless steel tension rod systems specifies as under:-
- The tension rod systems are intended for the use in structures with predominantly static loads
- The tension rod systems are not subjected to systematic bending.
- Design is carried out by the designer of the structure experienced in the field of steel structures.

All the above important stipulation were contradicted by the Designers of the Foot Over Bridge.

#### **6. Mode of Collapse**

The eye witnesses including workers engaged for concreting of the deck slab, reported that the concreting of the deck was started in the noon of September 21<sup>st</sup> by pumping of

readymix concrete from the road side. When about 50 m of the deck length was concreted they felt some sudden jerks sounding as “Karakk” and the deck slightly vibrated. Soon two of the suspenders at middle of the span suddenly snapped, shaking the bridge vigorously and triggering a chain reaction of snapping of all suspenders of both sides. The deck broke in three pieces and fell on ground with a thud shaking the ground like a mild earth quake. Some of the workers jumped off the bridge and others fell down alongwith the deck. Fortunately none was buried under the fallen bridge parts. The workers on the ground fled away as soon as they heard the sound of snapping of suspenders, shaking of the deck, cries of the workers and falling of the deck.

## **7. Actual Cause of Collapse of Deck Slab:-**

The undisputable cause of collapse, as indicated in the various Enquiry Reports, and studied by the authors, is tensile failure of the Retainer Screw of M -6 (Nominal rod diameter 4.5 mm) due to Bending moment caused in the Fork legs due to inclination of 9 degrees of the suspender and incorrect orientation of the Fork/ pin as shown in SKETCH – 4).

Due to inclination of the suspenders by 9 degrees to the vertical a horizontal force of about 1108 Kgs was generated and imposed on the leg of the fork of size 6.5 cm x 1.5 cm at the critical section due the dead weight of the steel deck, concrete laid, construction load and self loads of the suspender. This horizontal load subjected the leg of the fork to a Bending Moment of  $1108 \times 14 = 15512$  Kgcm while the moment of resistance of the fork leg was only 11213 Kgcm. The excessive bending moment transmitted a tensile force of 1108 Kgs on the washer of the pin which was further transmitted to the restraining M-6 screw which could sustain a force of only 574 Kgs only. The screw broke away by elongation, popped away disconnecting the suspenders from the deck, triggering a chain reaction of failure of all other succeeding and proceeding suspenders and falling down of the deck breaking in three pieces. The edges of the end pieces of the deck struck the ground on one end thus causing impact waves which damaged the connections and cantilevers. The central portion fell upon the road central verge and broke in two pieces as shown in Photo No. 2.

It is worthwhile to pinpoint that some other minor deficiencies in construction, as brought out by the consultants had no role to play in the collapse of the bridge as these were not found to be damaged after the collapse.

## **8. Inaccuracies in the Enquiry Report of the Dogra Committee:-**

The report is technically correct as far as the reason of collapse is concerned which is attributed to the asymmetrical loading more than permissible level which resulted into over stressing of Macalloy joint connecting the deck slab with Macalloy suspenders due to wrong orientation, that were imported from UK. However the authors differs with other contents of the report as follows:-

- Carrying out of the works in a great hurry, that too for laying of deck concrete, is in no way connected with collapse. All work was done by the contractor strictly as per the approved drawings. The design of the structures is required to cater to such eventualities. If any special care was required during construction of the bridge then it

was mundane for the Consultants to mention such cautions in the construction drawings and to be pointed out during routine site visits. Hind sight unsubstantiated comments are condemnable.

- The contractor did submit a detailed methodology for his work of fabrication and erection of the arches upon which no objections were communicated by the Owner.
- No methodology for installation of suspenders was necessary to be submitted by the contractor because being bought out items from the specified source the suspenders were to be installed as per manual of the supplier and drawings issued by the Delhi PWD under their supervision.
- Use of a slightly thicker plates, which were rolled within the permissible limits of thickness for the gussets was in no way responsible for collapse or any other eventuality. However such eventualities are required to be catered in the design calculations and drawings.
- The contractor did raise questions of deficiencies in design pin-pointing wrong orientation of the fork and the pin, the wrong fixity at both ends of the bridge and wrong welding of the deck with the arches at the meeting points etc. etc. during routine meetings with the owner and Designers.

Fairly and squarely the Designers were responsible for the collapse of the deck structure. The contractor followed best construction practices and is in no manner blame-worthy. Had the orientation of the fork pin kept in the direction of the deck collapse all the fuss made would have not happened.

#### **9. Comments on Design Aspects of the foot over bridge as per the study of the authors:-**

Failures are open books. The causes of failures can be accurately ascertained by checking of any design deficiencies, construction errors, use of bad materials, wrong application of new technologies, supervisory glitches and natural calamities etc. In this case there were several design deficiencies which lead to collapse such as:-

- Wrong application of the Macalloy 460 –S suspenders of 36 mm diameter against the instruction of the European Technical Approval.
- Wrong use of the suspenders which are meant for only static loads and not dynamic loads.
- Wrong orientation of the fork connection for a bridge which is subjected to dynamic loading.
- Wrong end connections of the suspenders with the box girder by providing a cantilevered cleat connection in lieu of simple bolted connections.

- Splaying the arches from c/c distance of 2.4 m at crown to c/c distance of 8.80m at the end supports on foundation was wrong which resulted in inclination of suspenders. Had the suspenders been vertical there could have been no Bending moment on the fork connection suspenders.
- Restrictions created by welding of the deck with the arches, at the deck level, and fixing the ends by anchor bolts to absorb the thermal expansion and moments was against normal practice.
- The arrangement of the suspended deck with suspenders is essentially a flexible structure which has been made rigid in detailing. The basic purpose of the fork connection was defeated.
- The detailed design of the joint of Macallay suspender with the deck of FOB in terms of asymmetrical loading and rotation of the gusset plate was not done.
- The consultants very well realized the mistake of using of a pin connection as seen from the design of connections of the other similar bridges, designed after collapse of this bridge, where nut-bolt replaced the pin connection.

Due to the above in-herent design deficiencies, inaccurate assumptions, lack of experience of use of new materials and technology, inelastic behaviour of connections, detailing errors and inexperience of detailor the **FOB was bound to collapse sooner or later**. Had the deck collapsed when under use of the spectators and athletes it would have resulted in catastrophe of gargantuan nature bringing national shame and possible fall of the governments!

### **10. Pinning Responsibility of collapse**

Modern bridge architecture is any thing but a breeze. The Designers and Architects keep on evolving new novel shapes and sizes which when accomplished become land marks. Modern bridges depict cultures and social ethos of the countries. Sydney-Australia is known for its Darling Harbour Bridge, New York is known for George Washington Bridge, London is known for its Tower Bridge and Millenium Foot Over Bridge, Mumbai is known for its Mumbai- Sea link bridge and Kolkatta is known for its Howrah Bridge. Innovations are always risky but without risk we don't advance. At the cutting edge, uncertainty is an occupational hazard.

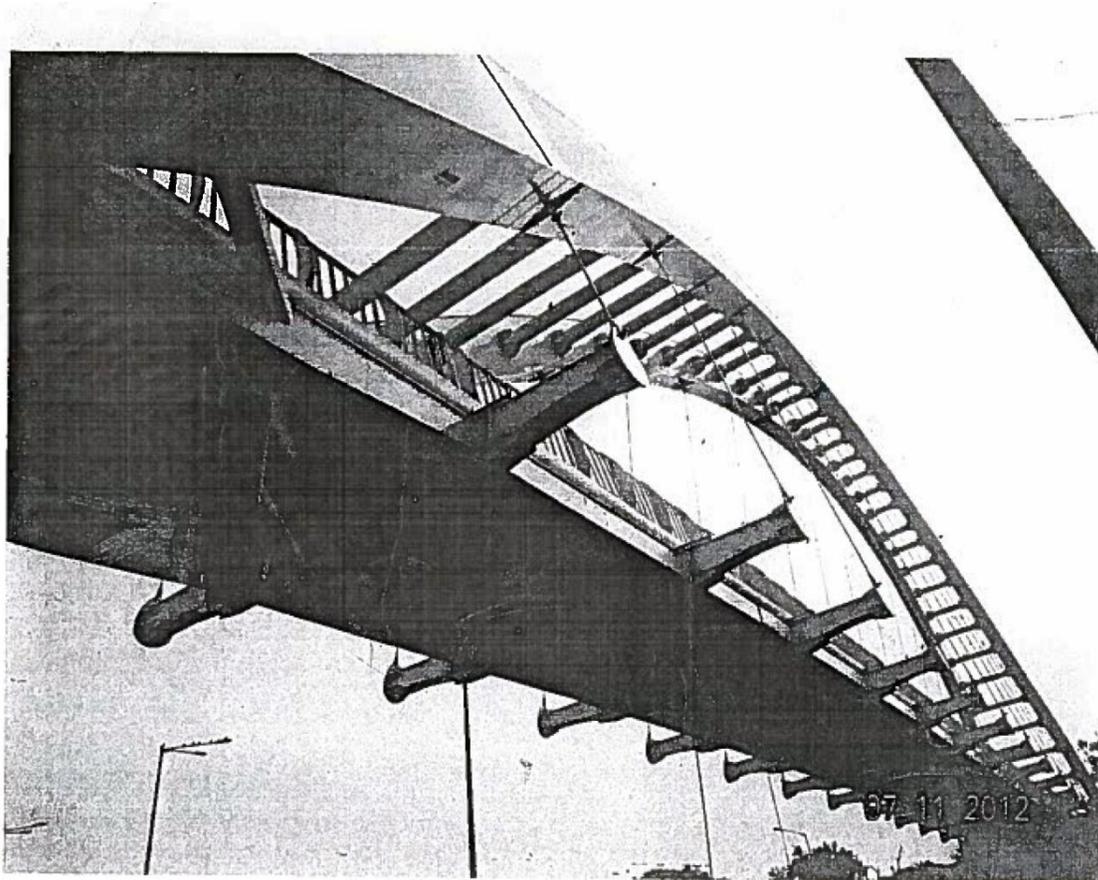
Though the design of the FOB, for main elements, was found to be over-designed, but errors crept in due to faulty connection details of suspenders. Such errors inadvertently occur in designs for which proof checkers are appointed. In this case the fault equally lies with the Designers as well as the proof checkers, who failed in detecting and pointing out the detailing deficiencies.

### **11. Reconstruction of the Foot Over Bridge**

The foundations and the paired arches of both the FOBs, costing about 70% of the total price of the bridges, were safe, sound and intact. The deck structure of one FOB was also

intact on which concrete was not laid. Due to collapse of the deck structure of one FOB 60% reinforced concrete laid on it were lost.

The re-construction of the FOBs was resumed after replacement of 36 mm dia Macalloy SS suspenders with high strength steel wire ropes of 80 dia, modification of pin connection to bolted connections, (Photo No. 5), provision of bearings at supports all proposed by the contractor. The completed FOBs were load tested by the contractor before acceptance by the Owner. Both the Foot Over Bridges are in use since February 2013 and have won “AWARD OF EXCELLENCE” (Photo No. 7).



**Photo No. 6: Showing the view of Completed modified suspender bolted connections**

## **12. Media Report:-**

On occurrence of such construction failures the country most active media immediately cries for throat of the contractor which is unethical and immoral because it causes immense harm to the reputation of the contractor who may be innocent. The responsibility of failure can be pin-pointed only after the actual causes of failure are ascertained after thorough investigations.

## **13. Lessons Learnt:**

- Bridge building is a risky business. Absolute safety for the design and construction of the bridges is unattainable. The risks of unintended and unwanted events are always present, but forewarned is forearmed. Use of new technologies and new materials necessitates thorough checks to ensure that the designs, drawings and detailing are correctly prepared to avoid loss of lives, interruption of traffic, costly repairs and replacements.
- The proof checking of designs should be assigned only to reputed experienced and competent consultants.
- The well experienced fabricators and erectors should be consulted by the Bridge Designer, to devise construction and erection methodologies which should be invariably be provided in the Construction Drawings.
- Adequate attention should be paid to accuracy of design parameters and assumptions, temporary erection arrangements and erection methodology, construction crew and competency of supervisory personnel and consultants.
- The suppliers of sophisticated materials of new technology like anchors, suspenders, hangers, bearings, expansion joints, prestressing materials and equipment membrane, roof sheeting, admixers, formwork, cranes, special paints, and lifting equipment etc. etc. should be consulted for complex bridge projects and new technologies.
- Adequate construction period should be allowed to avoid rush work or working in inclement weather to meet the dead lines.
- Free and frank communications among the consultant, fabricator, erector, construction crew and supervisory staff are essential for success of any bridge project.
- Third party inspection of materials and workmanship greatly helps in avoiding design deficiencies and construction errors.
- It is the duty and responsibility of the consultants, contractor and supervisory engineers to work as a close-knit team to avoid failures which bring bad reputation to the profession public wrath, bad publicity by media and irresponsible statements by politicians.

- Failures strengthen pillars of success for future structures when the lessons learnt are made use in design and construction.