The tay bridge disaster engineering essay

The Tay Bridge Disaster as the incident is popularly known , was one of the worst structure failures of the time both in terms of the size and significance of the structure and also was one of the biggest disasters as it took lives of 75 people. Such is the impact of the incident that it is intriguing the minds of experts and common people alike till date. Mainly because of the scale of the disaster but also because of the BOT inquiry which gave a detailed account of the failure but fell short of specifying how exactly the final collapse of the high girder section occurred leaving a mystery to be unraveled.

Talk about the likelihood of any compromises to safe design and construction occurring today and suggesting safeguards to prevent such practices

Discussion is based on the reliable accounts of the disaster by various forensic engineers with focus on original witness Evidence, systematically collected and preserved by the Court of enquiry. Original Pictures and other data from the reliable sources, duly acknowledged, has been included for the sake of illustration as is said -one picture is worth 100 pages.

Brief history of the disaster and the bridge has been provided at the beginning for better understanding.

SUMMARY/ ABSTRACT OF THE DISASTER:

” At approximately 7. 15 p. m. on the stormy night of 28 December 1879, the central navigation spans of the Tay Bridge collapsed into the Firth of Tay at Dundee, taking with them a train, 6 carriages and 75 souls to their fate.”

PMR Lewis 2002

“ collapsed high girders section girders were found almost intact close to the pierof the bridge, with twelve pier platforms almost bases, and laid out in a wave form alongsidecompletely swept off their high towers”

The famous lines by Peter Lewis quoted above sum it all up, it was a windy evening, a cross wind, a gale estimated at 10/11 at Beufort scale was blowing west to East and the ill fated Locomotive 224 driven by David Mathew was on time travelling from Edinburgh to Dundee with75 passengers onboard, the train hit the bridge at about 7. 15 p. m., accounts of two trains-passing the bridge before the fateful train are available, observers had witnessed sparks and lights from the bridge may be because of swaying of train and scratching against the guard rails.

As the train reached the “ High Girders” as they were called both train and the bridge were swept down to the Estuary, no soul survived the incident. It is not clear whether the train derailed before the structure gave in or it was vice-versa from the eye witness account as, Rail way worker John, only eyewitness who seems to have observed the whole sequence said-“ either the girders or the bridge is down” to the signal man.

1. 2. BRIEF HISTORY OF THE BRIDGE:

Opened in 1878, The Tay brdge, 2 miles across the Tay Estuary was the longest bridge in the world at that time and was remarked as “ latest engineering wonder” designed by Sir Thomas Bouch. Approved for safety by the Board of Trade, the bridge opened for only 19 months. It took six hundred men six years to build the bridge. It had been operational for almost

two years. It was designed by Sir Thomas Bouch who had a reputation for designing cost effective bridges.

An enquiry was entrusted to three judge court who were helped by two experts. The court announced its finding in record six month time holding Bouch , the designer responsible for the incident who was ripped of contracts for design for Forth Bridge and died a few months after the report of enquiry was made public.

2. 0. THEORIES OF THE COLLAPSE:

As stated the disaster has interested engineers, scientists and public at large, the catastrophe has been revisited by many and numerous attempts have been made to unravel the causes leading to failure of the bridge. Following four theories are prominent among them; although, the court of enquiry remains the source of original account as well as evidence. Which in my opinion is the basis of modern forensic engineering as it gathered, processed and preserved the evidence in a very systematic and professional manne. This was the first engineering inquiry to have ordered photographic survey.

Court of Enquiry

Blown by the wind theory

Train derailment theory

Fatigue theory

In order to investigate and analyse the engineering failings we shall discuss all these theories in brief:-

2. 1. COURT OF ENQUIRY:

Helped by two experts, the three member team was on the spot to gather witness evidence within five days of the mishap. They examined the witnesses, inspected the spot and the debris in detail, went into the maintenance aspect and also tested the material used in the best facility available at that time.

Recording their observations in 700 page enquiry report they concluded mainly on the basis of –

Eye witness account

Inspection of the debris

-they paid special attention to the cast iron lugs(which were twisted, fractured and broken see photo-1. 3 & 1. 4) which secured the braces and the nuts and the bolts (that were lying fractured)by which the braces were secured.

Testing of the materials in the lab

Design of the bridge

It was observed that the bridge was designed for wind load of 10 pound/square foot which was the minimum value provided to Bouch. It was noticed that designing the bridge for wind load higher than 10 would have needed dramatic change in design escalating the cost of the bridge.

Further compromises were made in the design on the cost of safety - changing the design of the piers from masonary to 8 columns of cast iron and then to 6 apparently to cut the cost of the project.

Construction of bridge

It was found that at least two piers fell while construction and were used after the repair/straightening.

Maintenance of the bridge.

Maintenance of the bridge was found to be poor even bolts were not tightened properly. And the structure was repaired improperly without informing the competent authority.

That the “ fall of bridge was occasioned by the insufficiency of the cross bracing and its fastenings to sustain the force of the gail”-see photo-1. 4.

The court belived that if the piers and the bracing were properly designed and constructed and maintained the bridge would have born the strength of the wind that night.

So Bouch was to be blamed who was responsible for design, construction and maintenance of the bridge.

Reviewed the observation of the court of enquiry in the light of modern knowledge relying on the “ the wealth of evidence surviving from the time, in particular the photographic archive and the court proceedings” to put in their words, and concluded that the court was dead right in its finding albeit they added oscillations produced in the high girder section that increased over

time as reported by painters and others could have been a significant factor that added to the increased fatigue in the lugs and the loosening of the bolts with time in absence of good maintenance.

2. 2 BLOWN BY THE WIND THEORY:

This theory was contributed by Tom Martin and IA Mcleod-they investigated the disaster using the modern computer analysis techniques in the light of modern approach to wind loading.

They used the mathematical model -“ three dimensional elastic frame computer model”-based on engineering drawings, court of enquiry report, Henry law report and results of component testing by the court of enquiry for testing the wind loading, to arrive at the conclusion that when the train reached the high girders the strong gust of wind created the upward lift uprooting the base of the windward side of the column which forced the diagonal tiles to fail at level 2 triggering the failure of the braces upward.

Tom has said that presence of train increased the lateral load and gave the explanation for -why only the high girders?- that lower girders were significantly short 100 feet to be precise hence the CG was low so was wind loading on them.

Fig. 2. 1(http://taybridgedisaster. co. uk/index/wind-theory)

Showing the stages of column failure due to wind

“ The bridge was examined with and without the train on the bridge to see what effect it had on the performance of the pier structure when subject to

wind loading. A pier was analyzed under various load conditions with a view to proposing a collapse mechanism."

" We found that the bridge was simply not strong enough to withstand the wind on that night. The marginally increased the overturning effect."

-Tom Mrtin IA Mcleod(http://taybridgedisaster. co. uk/index/wind-theory)

We know that it was the force of the wind that caused the bridge to collapse. I don't think the theory proves any thing new in relation to the court of enquiry.

2. 3 THE TRAIN DERAILMENT THEORY:

In the words of Bill Dow, retired lecturer in physics, the proponent of the theory-" Although there were probably many things involved, I believe that this derailment played a key role in the fall of the bridge. In short, I think that the rear carriages of the train derailed and ran into one of the cover paltes. The force of the impact would shatter the cast iron lugs leaving the bridge in high wind without its proper structural support."

The theory seems to corroborate the idea of Bouch as it proposes that the structure could have with stood the force of the gale.

According to the theory it was the derailment of the train caused by a kink and the force of the overthrown carriage produced the impact that triggered the fracture of the lugs connecting the braces leading to collapse of the pier structure.

Charles McKean in his book-‘ Battle for the North” sites this theory as the cause of the collapse.

The theory is based on two premises-

The wind was not that strong

Technical reports presented in the enquiry confirmed that the design of the bridge was adequate in relation to wind loading.

Obviously there are not much buyers of the theory as it tends to ignore the evidence on record as referred to in the discussion relating to court of enquiry inquiry

2. 4 THE FATIGUE THEORY:

This theory attributed to Dr. Peter Lewis, claims that the failure of the cast iron lugs are fatigue related. As the signs of fatigue could be seen in the lugs.

As we have already discussed the paper by Peter lewis and Reynolds they have applauded the efforts of the court of enquiry and have accepted the inherent weakness in the structure making it unable to withsand the wind load the bridge was subjected to that fateful day as the main cause of failure of structure.

They have tried to trace the factors such as dynamic effect by increased oscillation of the rails and the fatigue caused in the lugs that would have contributed to the failure.

Hence assigning the fatigue in the lugs as the primary cause of the engineering failure is undue exaggeration and is hence not justified.

3. 0 ANALYSIS

Having investigated and analysed the facts and circumstances of the disaster and the theories proposed it can be safely inferred that the faulty design leading to various deficiencies/defects in the structure outlined in the following table:

Was the primary cause of the failure of structure. We know that wind played a role in the collapse but although the computer simulation and other modern designing tools were not being used that time yet the technology and civil engineering know how of the time was perfectly capable of handling such wind speeds. Designing the bridge for the wind load of 10 pound/square foot was a blunder as we know that American and French engineers were using 20-30. Although the designer was provided wind data he used the minimum value , but every structure engineer knows the basic rule- play safe-under estimate the strength and over estimate the load especially so in the case of live and dynamic load like wind and moving train. However, we should not blame the designer for a low safety factor as the safety factor of 4 or5 was the norm then.

Various theories have proposed other plausible causes of bridge failure such as derailment, oscillation, wind and others but we know that a strong structure would have withstood all that as is evident in the fact that train moved up to the problem area i. e. High Girders perfectly safe in that high wind and with all those factors acting at that time. In fact every theory re

confirms the finding of the court of enquiry that inherent weakness of the structure was the primary cause of the failure they have just tried to explain the factor which according to them played the key role in testing the strength of the structure. What they intend to propose is the collapse mechanism-an exact sequence of events that occurred on the fateful night, the point which was not made very clear by the enquiry.

More unfortunate are the circumstances that lead to the faulty design as it appears from the available evidence that bad engineering practices and ethics resulted in the faulty design and construction of the fact-

It appears that the good design was compromised for cost cutting measures as we know that designer was under pressure to keep the costs down. Although it would have taken major change in designing the bridge for higher wind load such things like the size of the abbot other bases of the pier were also compromised which could have had (and eventually had) vital impact on the safety of such an important structure. Sir Thomas Bouch had a reputation as an cost effective designer and builder. He had also won the contract for the Forth Bridge which was later cancelled as a consequence of the disaster and findings of the enquiry.

It is a shame that even the basic engineering practices like good fastening and securing which did not involve cost were ignored. As Henry Law, one of the experts hired by the court, observed that the bolts were loose fitting and the photos, photo-1. 6 below depicts that even washers were not used and the nuts were not tightly secured showing a pathetic state of maintenance considering the size and significance of the structure.

A faulty design was followed by the faulty construction it has been documented that two of the Piers fell in to the estuary during the construction which were reused after straightening them.

A meticulous monitoring and maintenance schedule should have been followed considering the fact that the bridge was taking heavy traffic and high winds. But it appears from the evidence that the maintenance was not proper and even the maintenance procedure was faulty as the important things like fault in the structure was not reported to the incharge and was repaired in correctly.

This disaster changed the way the bridge were designed and constructed but it was not the last bridge to have failed due to wind force on account of bad design or wrong calculations, the fall of Tacoma Narrow bridge in 1940 is a classic example. Nick named Galloping Gertie, owing to its twisting and rolling behavior, designed by Moisseff who put solid steel girder beneath the road way to strengthen it, which were found to blocking the wind and causing the bridge to twist the defect in design (but the safety was not intentionally compromised) lead this massive structure to collapse on 7th Nov 1940 just 4 months after its opening.

But the design was not compromised in the case neither any bad practice or ethics was involved.

4. O ROLE OF MODERN PROJECT MANAGEMENT IN HELPING PREVENT SUCH ERRORS AND BAD PRACTICES AND ETHICS AS COULD LEAD TO DISATERS LIKE -TAY BRIDGE

As we see that the procurement related to the bridge seems to follow the traditional master builder approach as Bouch was the master builder responsible for design, construction and maintenance of the bridge.

But in modern construction industry the role of Project Management has increased as it is not uncommon for the employer to hire a management contractor to over see the project for the employer or to hire a project management team that looks after management of all the aspects of the project right from the initiation up to closing of the project(see Fig 2. 2 below)

There by incorporating multi point responsibility and avoiding single line administration. As the present PM focuses on team work, collective responsibility and professionalism, the chances of error in judgment leading to bad design and construction have been substantially reduced. In cases of huge projects like “ Tay Bridge”, it is a common practice before initiating a project to check for its viability taking help from the professional consultants and it is not uncommon to have second opinion and even involving more than one organization in the role of conceptualization and the design. One of the jobs of the professionals is to advise the employer about the additional budget provisions and cost over runs that may arise due to design and other problems in due course of the project.

4. 1 THE KEY FEATURES OF MODERN PROJECT MANAGEMENT THAT HELP PREVENT BAD ENGINEERING PRACTICES AND ERRORS LIKE COMPROMISE ON SAFETY FOR COST CUTTING ARE:

Identify and analyse the requirements with particular reference to viability and safety of project.

Research and review the current scenario

Detailed final analysis of costs and benefits with reference to the budget

Detailed planning

Identifying deliverables and staging

Identifying the activities and resources needed to complete identified deliverables

Scheduling

Estimating time, resources and cost to complete the deliverables

Allowances for time and cost over run

Developing the budget

Risk Planning

Measuring and monitoring on going project activities

Identifying and execution of corrective measures to address issues and risks

Identifying, monitoring and influencing the methods that could circumvent integrated change control

Maintenance -continuing support to end users

Corrections of errors

5. 0 LIKELYHOOD OF REOCCURRENCE

Although conventions and law for safety of structures is very strict these days but in the world of cut throat competition and employers concern for cost . priority tto the budget of the project and quest for supremacy and pushing the limits , There is every likelihood that compromises to safe design and occur today.

In fact we have many reported structural failures occurring even today because of compromising the safety and bad and unethical practices-

In the recent Potters Bar Accident-10may2002-the cause of the derailment of the last coach of the passing train was ascertained as-poor maintenance , leaving the bolts on points near the station loose. I would like to quote another very recent example from my own country India where during the construction phase of Delhi Metro Rail, an ambitious project underway in capital of the country-

“ On 12th July, 2009, while lifting segments of the superstructure, an accident happened in the Badarpur – Secretariat section near P-67. The pier cap of pier P-67 got collapsed causing subsequent collapse of the

(i) Launching Girder

(ii) Span between P-66 and P-67 which had got erected and pre-stressed, already

(iii) Segments of the superstructure for the span between P-67 and P-68.

The incident left 6 people dead and many injured.” -.(www. engineeringcivil. com/theory/civil-engineering-disasters/HYPERLINK “ http://www. engineeringcivil. com/theory/civil-engineering-disasters/ ”)

Investigations revealed one of the causes as-“ The pier (P-67) was initially designed as a leg of a portal frame and subsequently changed to support cantilever pier cap.” Apparently to save time and money at the co

6. 0 SAFEGUARDS TO PREVENT SUCH ERRORS AS COULD LEAD TO DISATERS LIKE COLLAPSE OF TAY

Need to stay on course. Once the problem is observed when the project is underway it should be dealt with following proper procedures and accepted practices. We need to stay on course we know that when unforeseen situations arise some times regarding the safety of the structure it self during the course of the project, professionals are under pressure due to various constraints particularly the time as the delay in execution would generally incur heavy penalties to the construction company and heavy losses to the employer, thisis where we generally deviate from accepted practice and procedure, usually in the guise of innovation and look for short cuts.

Creativity and innovation is the key to advancement and growth of any industry, but this should be encouraged during the conceptualization and

design stage when the new idea, practice or material can be fully tested in real as well as simulated conditions.

We know this happened with Tay bridge and even happens today.

There should be regulatory provision to get the big and/or significant structures passed for safety by more than one organization competent to do so. As we know the Tay Bridge was passed for safety by the Board of Trade but no one blamed the board for that. I think it was unfair to Bouch. Certifying/ passing authority should share the responsibility for the failure.

This would increase the measures for cross checks and counter checks. We cant leave the responsibility of human lives in the hands of one person (as was done in the case of Tay bridge) or in the hands of single organization as is the common modern practice in many cases.

Repairs and make shift arrangements- repair is an accepted practice during the maintenance phase although not advisable in cases where the component needing repair relates to stability or safety of structure but repairing a faulty component during the construction phase should always be avoided. We know from the recorded information that at least two piers of the Tay bridge which fell into the river and were damaged during the construction were straightened and reused.

Ethics discouraging bad practices should be encouraged, inculcated and incorporated in the professionals both at the academic and professional stage. Universities, industry and the institutes and organization related with

industry such as Institute of Chartered Civil Engineers should work on this in a co-ordinated manner.

As it was unethical on part of the Bouch to compromise safety for budget. And it was a bad practice and unethical to use repaired piers on a new bridge of this dimension and significance, it was bad for any bridge or structure infact.

It was bad engineering practice to not have put a procedure in place making it mandatory for inspectors to report any deficiency or defect in structure to the proper authority and take clearance and guidance from him for undertaking potentially major repair and maintenance

7. 0 CONCLUSION

Study of the Tay Bridge Disaster with focus on identification and analysis of causes of engineering failure has been attempted successfully. In the discussion the causes of failure have been identified and analyzed in detail. It has been concluded that the human error not the wrath of nature was primary cause of the disaster.

Causes of failure, in particular the compromising design to the extent of safety of the structure in order to cut cost has been discussed with reference to the chances of reoccurring of the blunder in present scenario in the context of modern Project Management; and is concluded that though the chance of reoccurrence of such errors have greatly been reduced in the light of role of modern Project Management practices but can’t be ruled out altogether, the point is illustrated with the help of recent disaster from India.

Safeguards have been suggested to prevent such reoccurrences to end the discussion with a positive note.