FORENSIC INVESTIGATION FOR SUSTAINABILITY ISSUES IN STRUCTURE

Prof. D.S.Bhosale

ABSTRACT- It is well said that, "Every contact leaves a trace". Technological innovation and advances in engineering have always been attended by failure of one type or another, including collapse of structures such as bridges and dams, multistoriey buildings,underground construction involves a number of uncertainties and risks, Construction failures which may carry a considerable price tag for developers, consultants and contractor in terms of structural rehabilitation and loss of business or life and could well lead to dispute and litigation process. Infrastructure plays a major role in the economy of a country and the failure of such structure will affect the economy of country. Investigation details of such failure will provide many lessons to construction professionals from past failures so that recurrence of such failures could be eliminated or minimized. **Forensic Engineering** is the investigation of materials, products, structures or components that fail or do not operate or function as intended, causing personal injury or damage to property. Forensic engineering is useful to develop practices and procedures to reduce the number of failures, to disseminate information on failures, and to provide guidelines for conducting failure investigation.

Index Terms - Economy, Failure, Forensic Engineering, Investigation, Risk investigation construction, Technological innovation, Uncertainties, Underground construction.

1. INTRODUCTION

THE most prominent single reason for failures which emerged was grossly inadequate appreciation of loading conditions or real behavior of the structure. Thus the apparent inability of designer or the contractor to appreciate how the structure will react to the loads was the main reason. It would be observed that this is not associated with the design safety factor which is being applied. However, the answers to the questionnaire constitute the assessment as to whether the incorporation of partial safety factors, at the present design levels, would be likely to influence the matter, and the apparent conclusion is that they would not significantly have done so.

Bad erection procedures are next in importance in causing failures and perhaps if the building is not well designed in the first place, any defect introduced by construction will only hasten the onset of failure.

Lack of communication in the construction industry is one more vital point. In the past, criticism about the general inability of the people, involved in the design and construction process, to develop a clear and unambiguous transfer of information necessary for the building project is observed. Thus, it is important on the part of the client to appoint competent, suitably qualified person to supervise, design and construct the building. Lack of experience, foresight or imagination is the common weaknesses of persons involved in the construction project. There is ample and serious condemnation of the present system in the industry, as well as of the education and training which the engineers undergo. Lack of recognition and incorrect procedures, are generally contributory factors to inadequate and ineffective communication between the parties involved. General analysis of failures would indicate that, inadequate thought and attention is given to the transmission of vital information between the parties involved in the building process. This has become increasingly important when we move away from the well understood traditional materials.

• *Prof. D.S.Bhosale Assit. Professor,Civil Engineering Department, Sou.Sushila Danchand Ghodawat Charitable Trust's, Atigre, Kolhapur, Shivaji University, Kolhapur,India, PH-09860237068*

More and more of the building components require careful study and assessment by the engineers, as to their suitability, of manufacture and erection. Furthermore because the building industry now contains so many different technologies and relies on people with different training and abilities, there is an ever-increasing need for effective communication.

The bridge between design and construction needs to be strengthened to create a two-way flow of information .Lessons learnt on it, need to be fed back in the design process and vice versa.

Financial problems often adversely affect the design and construction process especially with decisions delayed or reversed out of sequence with the network requirements. It is particularly so on large particularly so on large projects which seem to have their own relentless determination to end in catastrophe. How universally it is true! The term leader with strong and persuasive personality is therefore essential. He must be capable of reconciling use requirement, with good building design and construction awareness and perception.

1.1 HOW TO AVOID FAILURE?

Getting information from the structure either in use or collapsed, is an art requiring highly developed and sensitive understanding of structural engineering , material science and behavior of structure .Once the designer establishes a report with the structure, it conveys its health condition to the engineer. Depending upon the engineer's involvement and knowledge, he can interpret fairly correctly the trouble spots in the structure. It is more important that the observations like instability, inharmonious matching of materials, defective specification and details,settlements, restraints and constraints, severity of secondary stresses acting on the structure are made from time to time and well in time, so as to compare with design assumptions. These observations would provide deeper insight in the actual problem. Many other parameters are also observed on site. Every failure is normally a combination of several factors and each time,the main contributor is different. This is why the failure problem becomes interesting through uncertainty prevails.

2. OBJECTIVE

The objective of the project is to study and find causes of construction failure to avoid recurrence of such failures. Also study an effective technology of investigation to:

1) Review construction failures investigation process and 2) Develop a modified and concise technique that would provide a more effective documentation process for construction failures.

In order to achieve this objective the study:

- Examined the failure analysis processes being used by forensic engineers for conducting failure investigations and developed recommendations for improving investigation techniques.

The purpose of this research project is to;

1) Provide engineers, architects and contractors with an overview of current literature related to construction failures.

2) Determine concept of forensic engineering in construction field.

3) Investigate the methods used for documenting construction failures; and

4) Provide members of construction industry with information and guidance on construction to improve the investigation process.

3. METHODOLOGY

Forensic engineering is an important tool of structural failure investigation but, still very less work is done on forensic engineering so it's necessary to study this effective tool of investigation in greater depth.

This project includes the following phases;

1) Conduct a literature review of construction failure investigation processes.

2) Methods and applications of forensic engineering in construction field.

3) Suggest a checklist to avoid geotechnical failure and formwork failure.

2.1 NECESSITY OF FAILURE INVESTIGATION

These observations become more educative and instructive than any other academic background. We learn much more from mistakes than success. There is tremendous amount of information in each of the failure studies. If we can properly document, it would assist in advancement of our knowledge, focusing our attention on the shortcomings. Engineers know that they learn more b experience than from theory. So, do contractors, architects and developers. They also err, but they analyze their errors quickly, keep them to themselves, permitting someone else to repeat.

Who can afford to have a non functional performance? Even small inadequacy in the performance of any particular element of the structure, may lead to the annoyance of the user. This in turn, apart from legal aspects, puts the reputation of the professional at stake. It is not restricted to individual only. With more cases of observed deficiency the entire profession gets a set-back.

For every major incident reported, there are many unreported small ones. These small incidents, probably because of their nature and being not so serious, do not make news or put us on our toes. Several small cracks, deficient local workmanship, not true –to-form and out of plumb element, and not so serious magnitude of the problem do remain, but we are used to live with such small deficiencies as if they are unavoidable in construction.

These construction errors and other minor design deficiencies, get sheltered under the cover of fully workmanship. This is very useful and handy screen available with the designers, so as to pass on most of it to the construction practices.

All the laboratory research is theoretical. No one can really explain why one structure lasted, while another with similar design and loading and construction specifications, collapsed. There are several other structures, which defy us to understand as to why they have not failed so far or even earlier. The data perused from each failure often turns out to be unique , contributing to experience. What we miss today is co-ordination and proper documentation of our failure observations.

3.1INVESTIGATION: TECHNIQUE AND OUTCOME

Investigations—for whom and how to make them useful has always posed a problem. Collection of information is important. It must be done in such a manner that it can be classified, codified and compiled in a way easy to understand and interpret in proper formats, so that useful guidance is available. It is easier to say this but difficult to implement. The approach of each Institution or Centre collecting information on the failure would be different or limited. 'All under one' information questionnaire is not possible. Specific data collection would be out of context for some other purpose. The factors involved in the process, though mainly technical, several other issues like political, legal, serviceability, accountability and responsibility, recommendation and so on, need to be considered. Also there would be several constructional aspects to be covered. Along with this confidentiality, costing, stage at which the failure occurred, if during construction or in use, might be covered in the format. Also, any unusual loading, misuse, deterioration, special activity damage, additions and alterations etc., may be also needed. Thus, to evolve the format, appropriate for all purpose information, may be difficult. A few formats developed by individuals, or by institutions and those which were specially used in the past for data collection, are presented in the Annexure at the end. This is just to offer some insight into the available formats, their limitations and possible new formats for future use.

After years of experience of investigations of several failures, it becomes almost an inbuilt aptitude to understand more in regard to prediction and pattern of failure. This is a relatively unknown branch of engineering technology or science.

The performance problem is normally attributed to shortcomings in design, construction materials or combination. It, therefore, becomes necessary to identify what must have gone wrong in the first phase. Though it is difficult to project interdependent reactions and actions of several deficiencies in various stages of the construction process, it is necessary to study and develop this understanding. If the first important cause is identified in order of seriousness, one would be in a position to place the next and the next, in order of seriousness. One damaging effect may lead to explore the weakness of some other activity, either due to wear and tear or reduced factor of safety or self reduces strength. The most important aspect in the process is to clearly bring out all factors which would have affected the structure and caused it to fail. Such factors should be in order of their merit and sequential contribution. All this process of continued damaging effect, and reduction in the strength of the structure and subsequent reduction in the factor of safety, would establish the importance of monitoring of the structure. One such format for monitoring the structure is also attached in the Annexure at the end.

3.2CONVENTIONAL METHODS OF STRUCTURAL FAILURE INVESTIGATION

'Inspection of failure structure' is one of the conventional methods of investigation to find out causes of failure. This inspection generally expects observations, technical assessment, damage causing sources, present safety levels and recommendation for restoration with a block cost-estimate about the restoration and its phasing. This report is submitted to the clients in appropriate format. The report may contain written text, figures, sketches, drawings of existing structure, proposed work, and photographs etc. and invariably expects to comment on duration, sequence of repaires and block estimate provisions. This is a safeguard against tendency for mass scale repaires in the form of entire replaster, major guniting/shotcreting, and at times entire waterproofing to be replaced etc.

Common Observations which are helpful to find out causes of failure.

- External Façade
- Peeling of plaster and external/internal seepage marks
- Efflorescence, plinth protection, external drainage, ground water ingress, ground water floodin
- Overall response of plumbing
- Building has horizontal and vertical projections
- Terrace inspection
- Terrace housekeeping is poor
- Left RC column stubs
- Innovative user observations
- Option for waterproofing
- Incorrect drainage channel slopes in industrial structures

4. AN EFFECTIVE TECHNOLOGY OF INVESTIGATION

The professional engineering investigation work carried out in these cases has come to be described as FORENSIC ENGINEERING.

This paper discusses the general nature of forensic engineering and the special issues and difficulties confronting forensic geotechnical engineers, particularly in the investigation of failures or collapses in underground construction and underground mining. The investigation methods used are outlined and the important interface with legal systems is discussed. In the author's experience of forensic investigations in underground civil construction and mining, this legal aspect of the forensic engineer's role is becoming increasingly important and demanding, given the increasing proclivity of some authorities to prosecute engineers and their employers in the courts

Forensic engineering within civil engineering involves the investigation of failures of construction facilities and the built environment. While collapses are the most spectacular and potentially lethal type of failures - particularly when caused by criminal acts such as terrorism and arson - the discipline also includes investigation of failures in serviceability and performance, both during and after construction.

The key to forensic engineering is that the investigation practice and procedure should be sufficiently robust to stand up to rigorous scrutiny. It needs to embrace examination of a range of technical and organizational factors that may have contributed to a failure, especially where it results in claims and litigation. There is also a wider benefit in that the outcomes of forensic investigation and assessment can increase the sustainability of infrastructures by prolonging its use.

The failure report on the forensic investigation of everything from collapse to cracks in a diverse range of structures in the world, with causes includes blast, fire, storm, flood, erosion and corrosion.

Forensic analysis in geotechnical engineering involves scientific and legalistic investigations and deductions to detect the causes as well as the process of distress in a structure, which are attributed to geotechnical origin. Cases of remedied installations where the analysis and evaluation of adopted remedial measures with regard to their effectiveness and economy may be subjected to judicial scrutiny also fall under this purview. The normally adopted standard procedures of testing, analysis, design and construction are not adequate for the forensic analysis in majority of cases. The test parameters and design assumptions will have to be representative of the actual conditions encountered at site. The forensic geotechnical engineer (who is different than the expert witness) should be able to justify the selection of these parameters in a court of law. Hence he has to be not only thorough in his field of specialization, but should also be familiar with legal procedures.

A forensic investigation is the process by which the forensic engineering team gathers the necessary information to form the probable causes of the failure that has occurred . It involves "the application of the engineering sciences to the investigation of failures or other performance problems" where failures are "defined as instances when a structure does not conform to design expectations". Forensic investigation of pavements can help pavement engineers to determine the cause of premature failures as well as to develop appropriate rehabilitation strategies and to improve future design and construction practices. In determining the cause of failures, the principal goal is to determine the contributory mechanism related to an observed pavement failure as well as the events that may have caused the problem.

4.1WHAT IS DONE IN FORENSIC ENGINEERING?

For damage assessment in construction failure broadly two types of test are carried out-

1) Destructive Test -:

- Core sampling
- Drilled samples
- Steel sampling
- Pullout test

2) Non-destructive Test (NDTs)-:

- Rebound Hammer
- Ultrasonic pulse velocity(UPV)
- Sonic logging
- Mechanical impedance
- Re-bar locator
- Half – cell potential test
- Bulk resistivity

Dammage assessment through methodical tests permits the engineer to determine with reasonable clarity, true causes of damage and to measure its extent in structure and also to decide appropriate corrective measures.

5. RESULT AND DISCUSSIONS

It has been observed that, The key to forensic engineering is that the investigation practice and procedure should be sufficiently robust to stand up to rigorous scrutiny. It needs to embrace examination of a range of technical and organisational factors that may have contributed to a failure, especially where it results in claims and litigation. There is also a wider benefit in that the outcomes of forensic investigation and assessment can increase the sustainability of infrastructures by prolonging its use.

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Some guidelines to avoid Formwork Failures.

- Form work must be correctly installed, checked and periodically examined for its wear and tear and for correct position; incorrect intersections and connections should be checked.

- External ground, grade level, should be properly stabilized or concreted well in time before it receives shores of formwork.

- Individual shore should be braced in at least two directions with continuous runners, and must be cross braced for lateral stability.

- When formwork erected in position ready to receive the load of concrete pour, they should be sufficiently tight and safely nailed to prevent slipping. Special spacers should be provided for tall shores for more than normal floor height, one should use double or triple stage shores.

- Proper bearing provided for stringers and joists at supports, ledgers or stringers either firmly attached or bridged, laterally braced to prevent over turning, and their inspection become necessary.

- High shores, susceptible to failure, must be diagonally braced.

- Shocks and vibrations from the use of concrete trolleys, runways, powered buggies must be controlled, and also properly provided in the shores.

- Details that are difficult to perform, such as the overhead driving of nails to connect flat cap plates of a shores to unloaded wooden joists, will often not be properly performed and may start a failures.

- Forms are continuously supported structures and must be provided uniform bearing at each support and each end. Settled mud sills or disturbed timber shores splices, will completely upset the reactions with possible overloading of some shores and creating imbalance. This may trigger a collapse.

- Wedging of shores to counter balance the loads, must be done under proper supervision, so that a previously assembled form support, is no disturbed.

- Unbalanced stripping of form and unbalanced re-shore, will cause stresses in green concrete in locations which are not sufficiently reinforced or expected to develop the types of stress induced due to the activity. Permanent damage , cannot be ruled out.

- Adequate re-shore must be provided immediately and concurrently with stripping operations.

- Entire work needs constant and vigilant supervision of skilled foreman, assisted by designer/ engineer at site.

- As you go up one has to be more careful in his observation and inspection, since there would be more chances of slips and omissions due to re use.

- Role of bracing and lacing in single shoring system is not properly understood by many. Inadequate understanding has resulted in serious problems. Vertical shoring systems over 4 m in heights, presents critical exposures to failures, if proper precautions to cater to loading systems to which shores are subjected, are not taken.

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