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Overview of Forensic Engineering

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Definition

- **Forensic (fo ren' sik)** - the application of knowledge to questions of civil and criminal law. Forensic engineering is the application of engineering principles and methodologies to answer questions of fact.
- Forensic engineering is essentially a failure analysis program for litigation support. The goal of such a program is to positively identify the sequence of events leading to ultimate failure.

Forensic Engineering
Definition

- From Latin : *forensis* meaning “public”
  - Belonging to courts of law
  - Pertaining to or fitted for legal or public argumentation
- Forensic Engineering – a science concerned with relations between engineering and the law

Floor Slab Collapse

Collapse of third floor slab under construction at KL Central. Tuesday 11am, October 11th, 2011. Two workers injured.

Bungalow Renovation Work

October 19th, 2012. Section 7, Shah Alam. One worker died and 5 critically injured when the concrete slab collapsed. The owner is facing the risk of legal action for not having the renovation permit from Shah Alam City Council as per Section 70(1) of the Akta Parit, Jalan dan Bangunan 1974.

Collapse of Scaffolding in Stadium Repair Work

Collapse of Stadium Sultan Mizan, Terengganu in 2008

Collapse of the scaffolding of repair work on the same stadium in 2013, February 20th, 11.30am. Two workers injured (broken legs).

Collapse of Supermarket Upgrading Construction

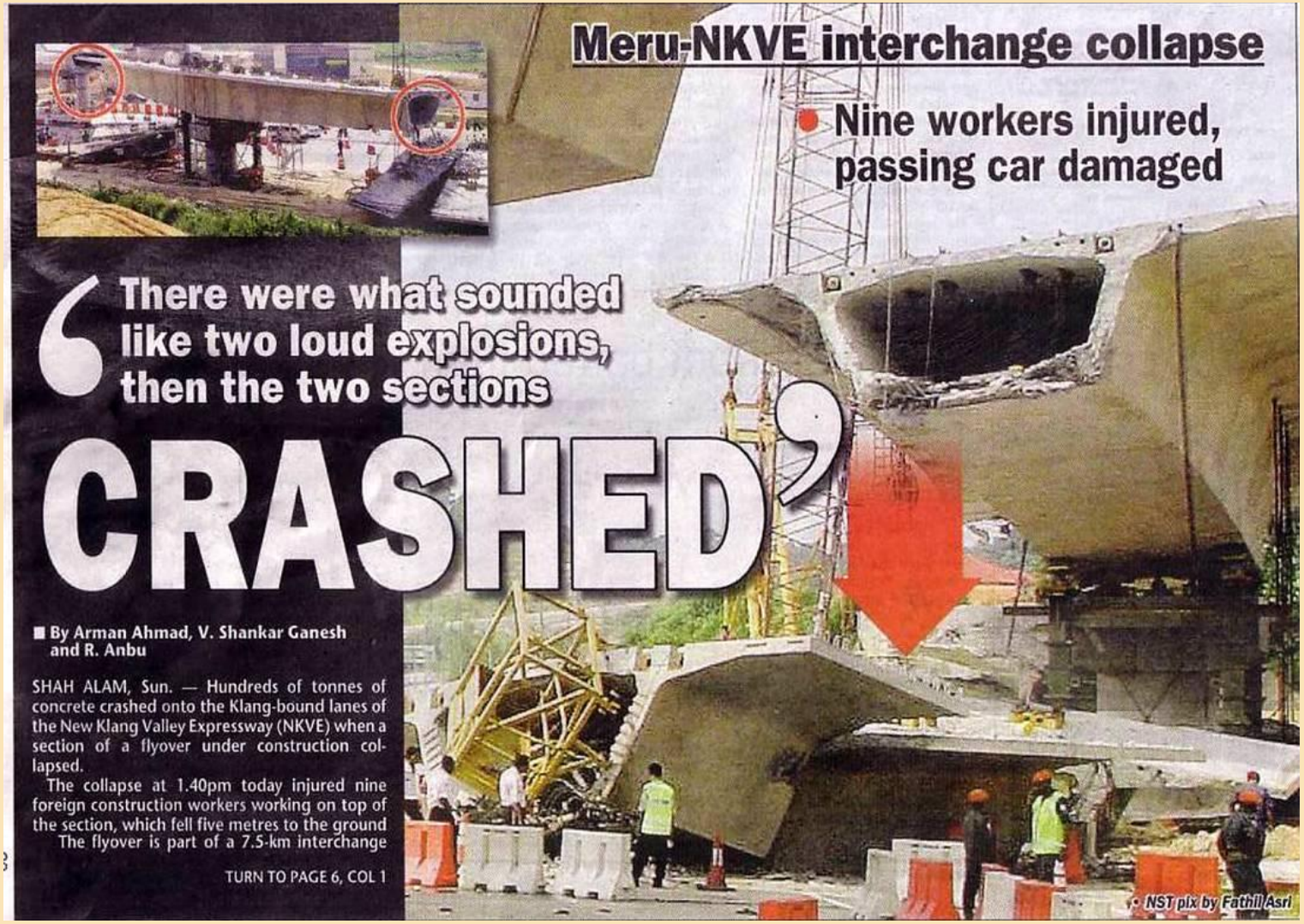
May 29th, 2009. Collapse of ne-third section of renovation and upgrading work on 35-year old Jaya Supermarket building, Section SS14 PJ. Three workers died and two critically injured.

Putrajaya Bridge Collapse

Collapse of Retaining Wall

Setiawangsa land slide forces residents of 88 houses, shoplots to evacuate. One luxury hilltop bungalow was split into two after the 43m retaining wall at Jalan Puncak Setiawangsa 2 collapsed, at 6pm 28th December 2012.

Box Girder Bridge Section Collapse During Construction



Meru-NKVE interchange collapse

- Nine workers injured, passing car damaged

'There were what sounded like two loud explosions, then the two sections

CRASHED'

■ By Arman Ahmad, V. Shankar Ganesh and R. Anbu

SHAH ALAM, Sun. — Hundreds of tonnes of concrete crashed onto the Klang-bound lanes of the New Klang Valley Expressway (NKVE) when a section of a flyover under construction collapsed.

The collapse at 1.40pm today injured nine foreign construction workers working on top of the section, which fell five metres to the ground

The flyover is part of a 7.5-km interchange

TURN TO PAGE 6, COL 1

NST pix by Fathil Asri

Roof Collapse

8th October 2005, NST: The roof of the multi-purpose hall at Sekolah Menengah Sains Sultan Ahmad Shah in Kuantan collapsed. It is learnt that the supporting aluminium structure and the roof tiles came down at 10pm.

Stadium Roof Collapse

Indon worker killed in stadium roof collapse

FALLEN ROOF: Indonesian worker Sumaidi was killed when the steel roof structure of the bowling stadium collapsed in Paroi, Negri Sembilan, yesterday.

SEREMBAN: An Indonesian worker was killed and four others seriously injured when the steel roof structure of the semi-completed state 10-pin bowling stadium collapsed.

The victim, identified as Sumaidi, 35, from Jakarta Barat, died on the spot during the 10.10am incident yesterday.

Four other workers were rushed to the Seremban Hospital and warded for multiple head and body injuries.

They were Azmi Mohamed, 22, of Changkat Jering, Perak, Mohd Zoher Salleh, 39, of Kampung Masjid Tiak, Kedah, Mohamed Anuar, 21, and Mohd Rosli Hayuddin, 23, both of Batu Kurau, Perak.

Several others escaped with minor injuries and were given outpatient treatment at the hospital.

OCPD Asst Comm Mohamad Abdullah said the incident happened at the construction site of the stadium in Paroi that was about 60% completed.

He said the five workers were fixing the steel structure on the upper level of the building when the roof gave way and collapsed.

A 17-year-old worker, who wished to be identified only as Ah Hui, said he was doing piling work when he heard a very loud sound before the roof came crushing down.

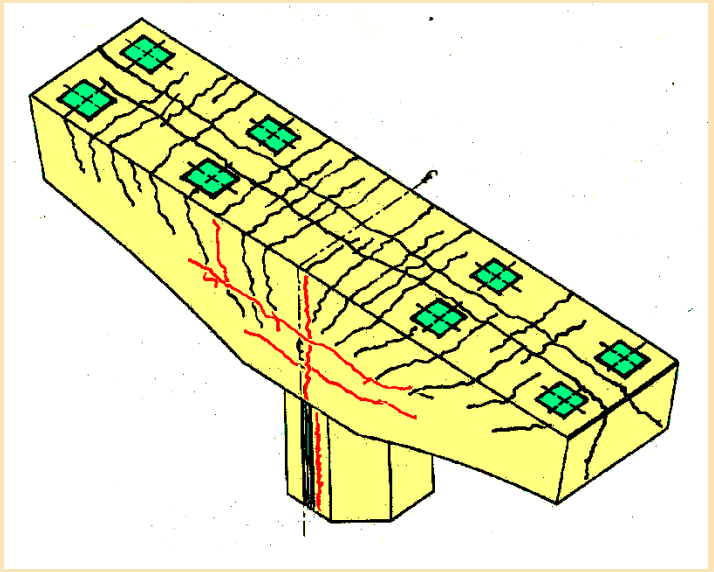
"I was not hurt as I was standing quite a distance from the site where the roof collapsed," he said, adding that he then rushed over to help the injured workers.

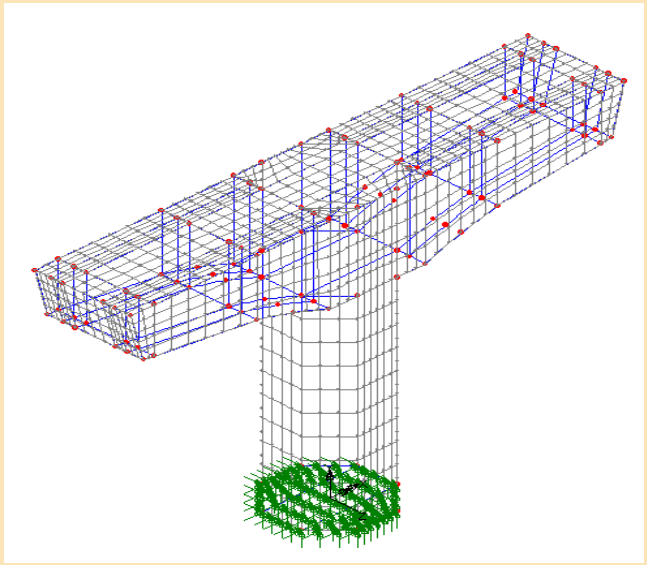
16th April 2005, The Star: An Indonesian worker was killed and 4 others seriously injured when the steel roof structure for the bowling stadium under construction collapsed. The construction site of the stadium is in Paroi, Negri Sembilan.

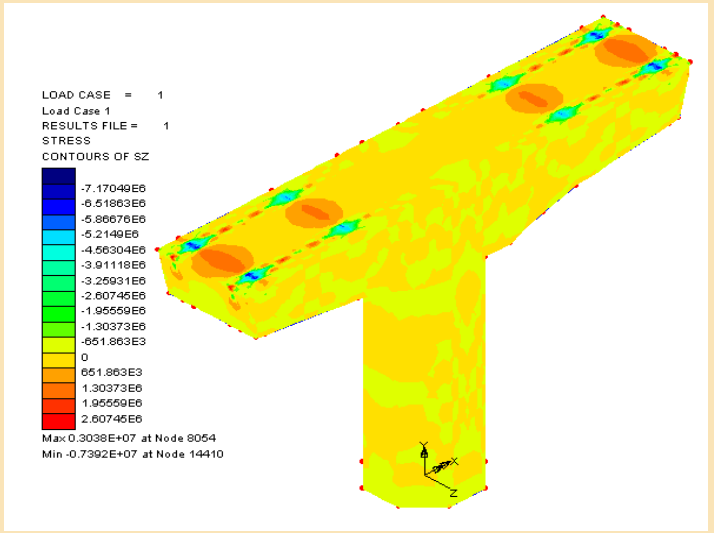
Collapse of Bridge Under Construction

Collapse of a Club House under Construction

Case : Cracking in Bridge Crosshead







Collapse of Luxury Apartment Building (The Highland Towers)

General Goals of Forensic Engineering Investigation

- To determine causes of failure (most commonly desired information)
- To compare statement by witnesses or injured parties with physical evidence
- To ascertain whether an illegal or improper activity was causative
- To assess damage to materials, products or structures and evaluate repair estimate

Multi-Disciplinary

- Forensic engineering is a multi-disciplinary process for investigating and reporting the cause of engineering problems which may have legal ramifications.
- The process is founded on the scientific method which is fundamental to the solution of most engineering predicaments whether they are related to civil, structural, geotechnical, mechanical, metallurgical, materials, industrial, chemical, or other engineering fields.

Who are the clients?

- Owners, developers, tenants
- Public & government agencies
- Contractors
- Designers, material manufacturers
- Attorneys
- Insurance companies
- Plaintiffs in litigation (injured parties)
- Defendants in litigation (design, construction, maintenance or operation)

Activities in Forensic Engineering Investigation

- Gather Information
- Investigate
- Visual Inspection
- Document Review
- Photographic Documentation
- Code, Industry Standard and Product Research
- Analysis Data
- Map Actions of Parties
- Develop Opinions and Conclusions
- Explain the reasoning behind the conclusion
- Prepare culpability worksheets
- Assist Attorneys
- Give a clear assessment of the risks involved with each issue
- Give Expert witness testimony

Diverse Fields of Forensic

- Forensic Accounting
- Forensic Anthropology
- Forensic Audit
- Forensic Computing
- Forensic DNA
- Forensic Entomology
- Forensic evidence
- Forensic Linguistics
- Forensic Medicine
- Forensic Meteorology
- Forensic Odontology
- Forensic Palaeology
- Forensic Palynology
- Forensic Pathology
- Forensic Psychiatry
- Forensic Psyhology
- Forensic Science
- Forensic Toxicology

Forensic Civil & Structural Engineering

- Engineering investigation and determination of the causes of structural failures of buildings, bridges and other constructed facilities;
- Rendering opinions and giving testimony in judicial proceedings.

Problem Statement

- Structural failures are not just accidents, nor acts of God. They are the results of human error originating from oversight, carelessness, ignorance or greed.
- With the relevance of design sophistication and construction methodology came the proliferation of structural failures.
- Early savings in design and construction costs often boomerang as later and larger costs of repair and litigation.
- The vulnerable structures of the late 20th century will provide bread and butter to the forensic engineers of the 21st century.

Dr. Robert T. Ratay, Forensic Structural Engineering Handbook, 2000

Scope of Forensic C&S Engineering

- Structures, buildings & bridges
- Geotechnical works
- Highways and transportation
- Waterways, ports, coastal & offshore facilities
- Culverts and pipelines
- Air transportation
- Environmental facilities
- Hydraulics, irrigation and drainage

Competencies of Forensic C&S Engineer/Investigator

- Familiarity with building codes, specifications & industry standards.
- Understanding of structural & soil behaviour to know how structures behave and why they fail.
- Ability to collect & analyse data (detective skills), develop failure hypothesis & reach to correct conclusions regarding the causes of failure.
- Having some knowledge of legal procedures.
- Good oral and written communication skills.
- Have high ethical standards.

Structural Failure – What is a Failure?

- General Definitions
  - Inability of a component, structure or facility to perform its intended function.
  - Failure does not necessarily involve collapse or rupture.
  - Non-conformity with design specifications or deficient performance.
  - *An unacceptable difference between the expected and observed performance.*

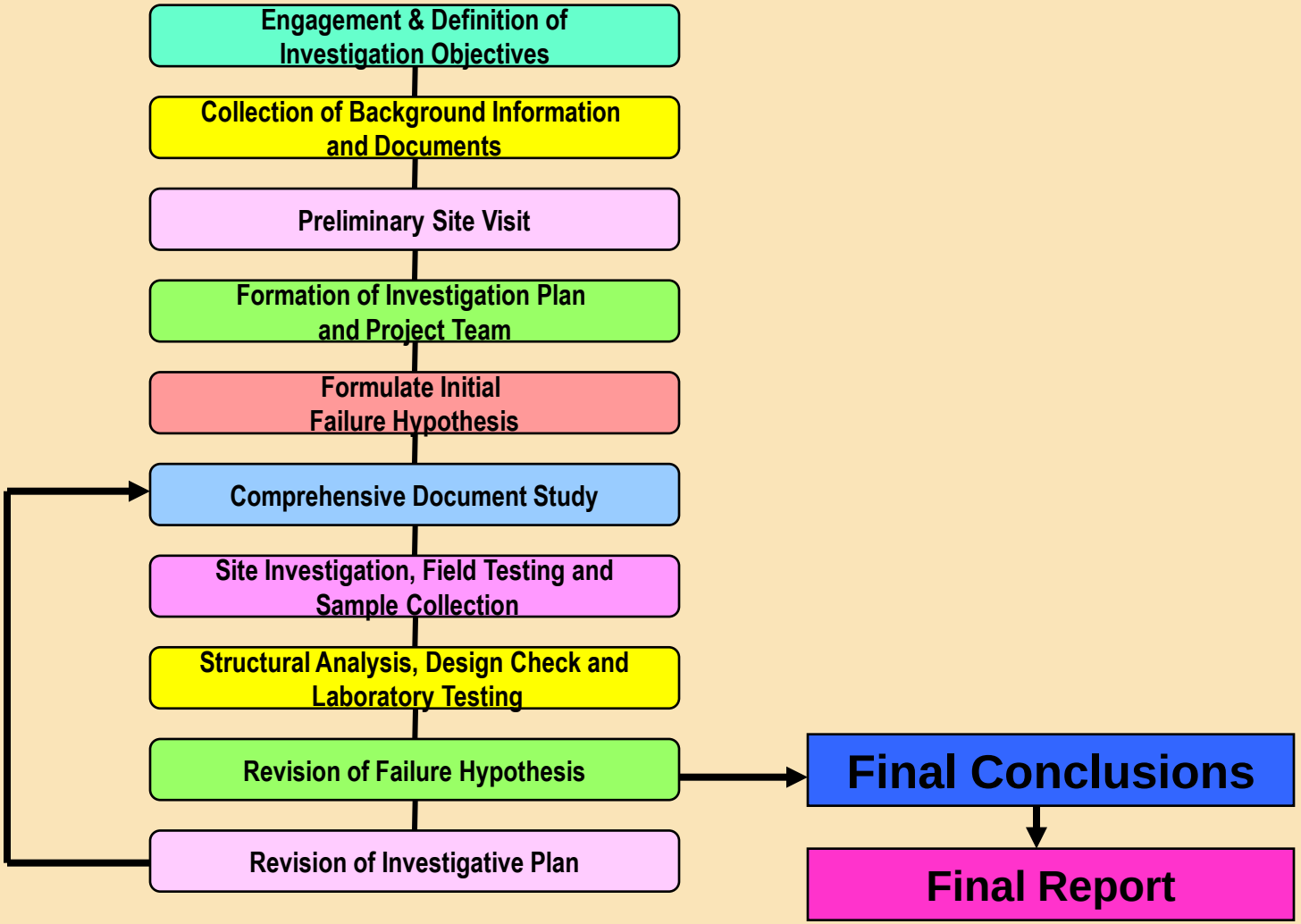
Functional Failure

- Functional failure involves compromise of intended usage of structure or facility
- Examples
  - Excessive vibration of floor
  - Roof leaks
  - Inadequate air conditioning
  - Poor acoustics

Causes of Failures

- Site selection and site development errors
- Programming deficiencies
- Design errors
- Construction errors / procedural errors
- Materials deficiencies
- Operational errors

The Investigative Process



Identify Investigative Team

Possible disciplines for structural failure investigation :

- Structural engineer
- Geotechnical engineer
- Concrete specialist
- Metallurgist / Material expert
- Architect
- Surveyors
- Photographer
- Test specialists, instrumentation specialists
- Contract law specialist

Site Visit

- Schedule as soon as possible, especially when collapse is involved
- Plan carefully
- Document findings
- Preserve perishable evidence – collapse configuration; features of fractured steel surfaces; test cubes or cylinders
- Failed and unfailed components

Equipment

- Measuring devices
- In-situ testing equipment
- Photographic equipment
- Clothing
- Data recording equipment
- Sampling
- Small handy tools

Collection of Samples

- Site should be carefully photographed and sketched
- Sampling techniques should conform to specified standard/codes
- Samples should be marked, referenced, catalogued, and stored according to procedures

Documenting Visual Examination

- Establish referencing system
  - Compass direction
  - Coordinate system
- Make liberal use of notes and sketches
- Make liberal use of photographs (film is cheap!)
- Document photos
  - Arrow on plan of structure
  - Careful description in notes
  - Camera with number imprint is very helpful

Eyewitness Accounts

- Passerby eyewitnesses may provide information on sequence of events (collapse)
- Project personnel – project managers; designers; foremen
- Interview workers or others knowledgeable of structure
- Seek photos or videos taken earlier of structure

What Information to gather from eyewitness

- Status of construction at time of failure
- The mode and sequence of failure
- Possible triggering events

  - activities under way at the time of collapse
  - unusual loading on structure
  - environmental factors
- The capacity of certain components or entire structure at the time of failure

Physical Tests

- Mapping of cracks & other defects
- Partially-destructive tests for concrete strength

  - Penetration resistance (Windsor probe)

  - Pull-out; pull-off; internal fracture
- Non-destructive tests
  - Rebound hammer for variability of material
  - Wave method for thickness and variability
  - Radioactive methods

Laboratory Analysis

Materials Testing

- Concrete samples
  - Petrography analysis
    - Chemical reactivity
    - Air content
    - Cement content
    - Water/cement ratio
  - Cores
    - Strength
    - Chloride tests
    - Existence of corrosion
    - Freeze-thaw tests

Components Testing

- Load tests
  - Connections
  - Structural components
  - Whole structure

Document Search

- Construction Documents
  - Plans and specifications
  - Contractual agreements
  - Progress reports
- Shop (fabrication) drawings and erection / as-built drawings
- Boring logs

Document Search

- Test reports
  - Foundation reports
  - Concrete materials test report / cube test
  - Steel test report
  - Post-tensioning report
- Manufacturer's certificate
  - Portland cement
  - Structural steel
  - Reinforcing steel
- Inspection reports

Document Search

- Project correspondence
  - Contractor
  - Engineer
  - Architect
  - Other consultants
- Engineer's design calculations
- Applicable building codes
- Weather records

Develop and Test Hypothesis

- Examination of photos, design calculations, and other evidence
- Perform additional calculations or design check
- Conduct laboratory tests
- Conduct test on structure

Prepare Conclusions

- Summary report
- State probable causes
- Provide support for conclusions

Dispute Resolution

- Civil Litigation (Lawsuits)
- Alternative Dispute Resolution
  - Arbitration
  - Mediation
  - Negotiation
  - Mini-trial
- Majority of cases are settled out of court (only 10% go to trial)

Legal Concerns after a Failure

- **Potentially responsible party** (e.g. design consultant, sub-contractor) – concerned with determining his legal exposure to injured parties;
- **Injured party** – concerned with preserving his rights against any potentially responsible party;
- **Project owner** – concerned with preserving rights against potentially responsible parties and having the project remedied and put back into use.

Dispute

Flyover collapse

INSIDE

DEAD END: Workers p

Ministry: NKVE link developer ignored safety rules

BY SHOM TEOH

PETALING JAYA: The developer of the NKVE-Jalan Meru Link neglected safety regulations by allowing motorists to travel on the road below the incomplete flyover that collapsed on Sunday, said Deputy Human Resource Minister Datuk Abdul Rahman Bakar.

"It's an offence to allow traffic on roads where there is construction, as this will expose motorists and the public to danger.

"Unfortunately, this is happening at many places around the Klang Valley. Rightfully, those sections should be cordoned off and detours should be created for traffic to bypass those areas.

"Safety should be our priority, in spite of the inconveniences we have to face," he said after opening an international conference, *Managing Future Workplace Issues and Challenges In The Borderless World*, organised by Universiti Teknologi Mara's Faculty of Management and Technology yesterday.

He remarked that the developer, SP Setia Bhd, and the main contractor it appointed, Chung Hyap Yoon Sdn Bhd, had failed to fulfil safety conditions when carrying out the project.

Nine Bangladeshi labourers were injured when eight girders of the flyover near Bukit Raja collapsed on Sunday.

In Seremban, Department of Occupational Safety and Health (DOSH) director-general Abu Bakar Che Man said he would seek a report from SP Setia on how the company intended to dismantle the remaining structure of the collapsed flyover, reports **SIMON KHOO**.

"Although the debris on the road had been cleared, parts of the elevated interchange at the Meru Link are still hovering precariously.

"Since the Bukit Raja-Shah Alam stretch is expected to be opened by Thursday, all measures must be taken to ensure it would not endanger passing motorists," he said after opening a seminar on safety and health management.

Abu Bakar said DOSH would send several officers to assist the Public Works Department in investigations into the cause of the flyover collapse.

Meanwhile, after further discussions with the authorities yesterday, SP Setia said it would submit a follow-up report with more detailed information by today.

"We are working closely with the external specialist contractors and consultants to prepare the follow-up report and will hand it over to the authorities," said Khor Chap Jen, a director of SP Setia.

Engineering Firm Sues Utusan for Libel

Saturday, March 18, 2006

Civil Engineering Design Consultant, Maunsell Sharma & Zakaria, the consulting firm for the design of Ampang-KL Elevated Highway (KLT) has sued Utusan Melayu (M) Bhd for RM50mil for libel. Maunsell Sharma & Zakaria Sdn Bhd, filed the suit at the Civil Division High Court registry at Wisma Denmark in Jalan Ampang here yesterday through their lawyer D.P. Vijandran.

In the suit, the firm claimed that the Utusan Malaysia daily had published defamatory words in two page-one articles on Feb 9 and 10. It said the articles alleged that there were many cracks in the highway and that these were caused by flaws in the engineering design of the highway.

Apart from damages, the company is seeking an injunction, an apology, interest and costs.

Maunsell Sharma & Zakaria is also the design consultant for Middle-ring Road Two (MRR2).

‘Cracks due to Design’ – Works Minister on MRR2 Flyover

Yesterday (March, 17, 2006), Works Minister Samy Vellu admitted in Parliament that defective design was one of the reasons for the cracks in the Middle Ring Road 2 (MRR2).

"The steel placement did not follow specifications," Samy said in reply to a question from Speaker Tan Sri Ramli Ngah Talib.

Ramli had interrupted Samy Vellu when the minister was giving a technical explanation for the cracks on the MRR2 highway in reply to questions from Datuk Ismail Sabri Yaakob (BN-Bera) and other MPs.

Samy Vellu said his ministry monitored bridges and flyovers but only the MRR2 was found to have "serious defects".

Public Accounts Committee

Repairs to MRR2 flyover cost RM70m

THE Public Accounts Committee (PAC) has revealed that repairs to the MRR2 flyover in Kepong cost more than RM70mil, *Utusan Malaysia* reported.

PAC chairman Datuk Shahrir Abdul Samad said the figure was high compared with its construction cost – RM120mil.

He was quoted as saying that this reflected "shoddy design and construction concepts" that were approved by the Government when projects were given to contractors.

"There is no point in spending more and not being able to use it," he said, adding that it was difficult to pinpoint who was responsible for the mistakes in such a project.

"As an example, the MRR2 project has the contractor and concessionaire constantly pointing fingers at each other. The problems were with the design and construction."

OTHER
NEWS & VIEWS

Compiled by ROYCE CHEAH, BEH YUEN HUI and A. RAMAN

> *Kosmo!* reported that residents in Ipoh claimed to have seen an unidentified flying object (UFO) after similar reports were made by those in Kampung Terap, Kulim and Seberang Jaya.

Taxi driver Mohd Helmi Hashim, 35, said he was in the midst of sending a passenger from Medan Gopeng to Pengkalan Gate when he saw an object streak through the sky at 6.20am on Monday.

»I was shocked to see the object move so quickly«

MOHD HELMI HASHIM, CABBIE

"I was shocked to see the object move so quickly. It must have been moving at around 300kph-500kph," Mohd Helmi said, adding that the object was orange in colour and was so bright that the dawn sky became clear as day.

Another person, Azmi Lazim, 34, from Sungai Siput, claimed that he saw a UFO while he was passing Chepor, about 5km from Chemor, the daily reported.

> *Harian Metro* reported that a wayward *bomoh* from the Philippines claimed to be able to make money fall from the sky and conducted his own *akad nikah* (marriage) ceremony with an Indonesian woman recently.

The 45-year-old man is said to have performed *akad nikah* ceremonies for a number of couples in the Old Klang Road area in the past year, where no documents were signed.

A source named Harun said the man would give the excuse that he would get the related documents for the couples in the days following the ceremony but did not do so.

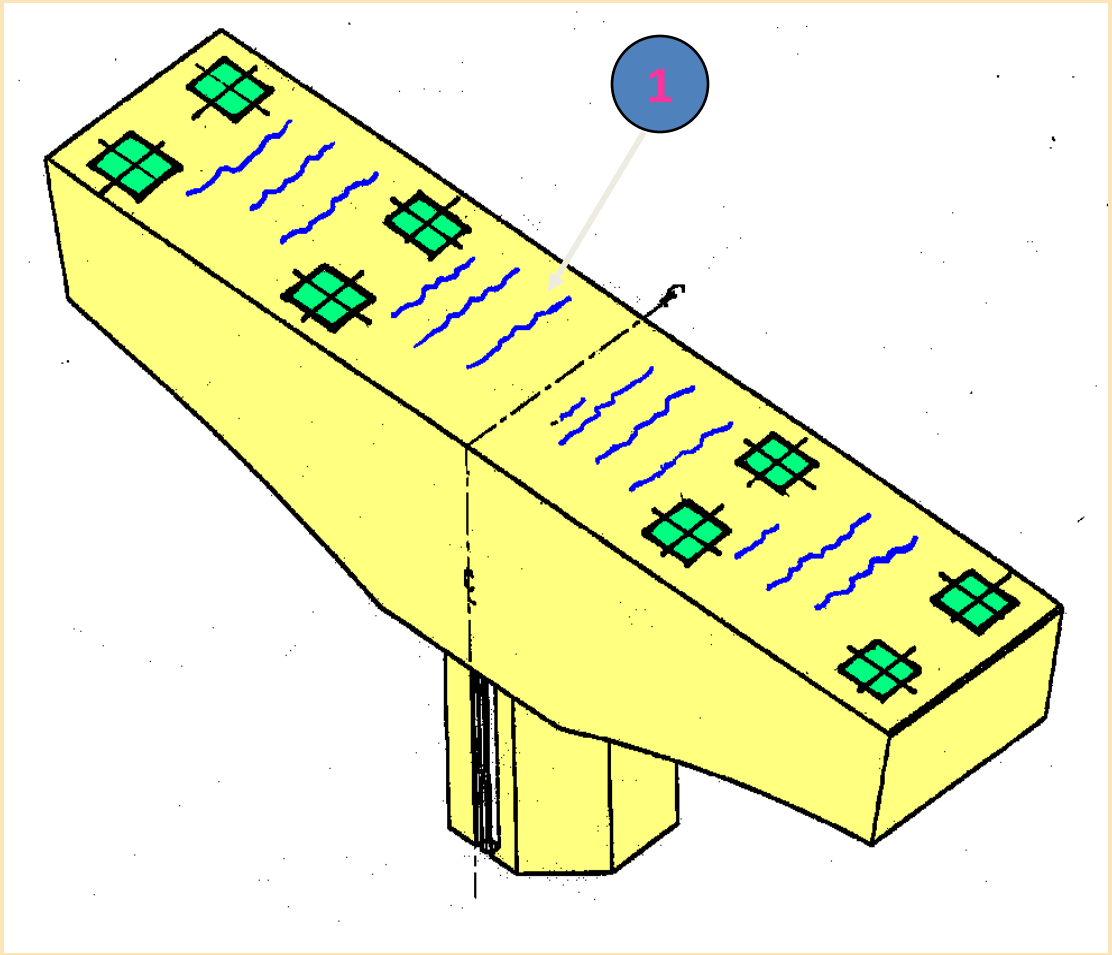
Forensic Engineering Case Study 1:

Extensive Cracking in Elevated Flyover Bridge

Case Study 1: Extensive Cracks in 33 Pier-Crossheads of an Elevated Bridge

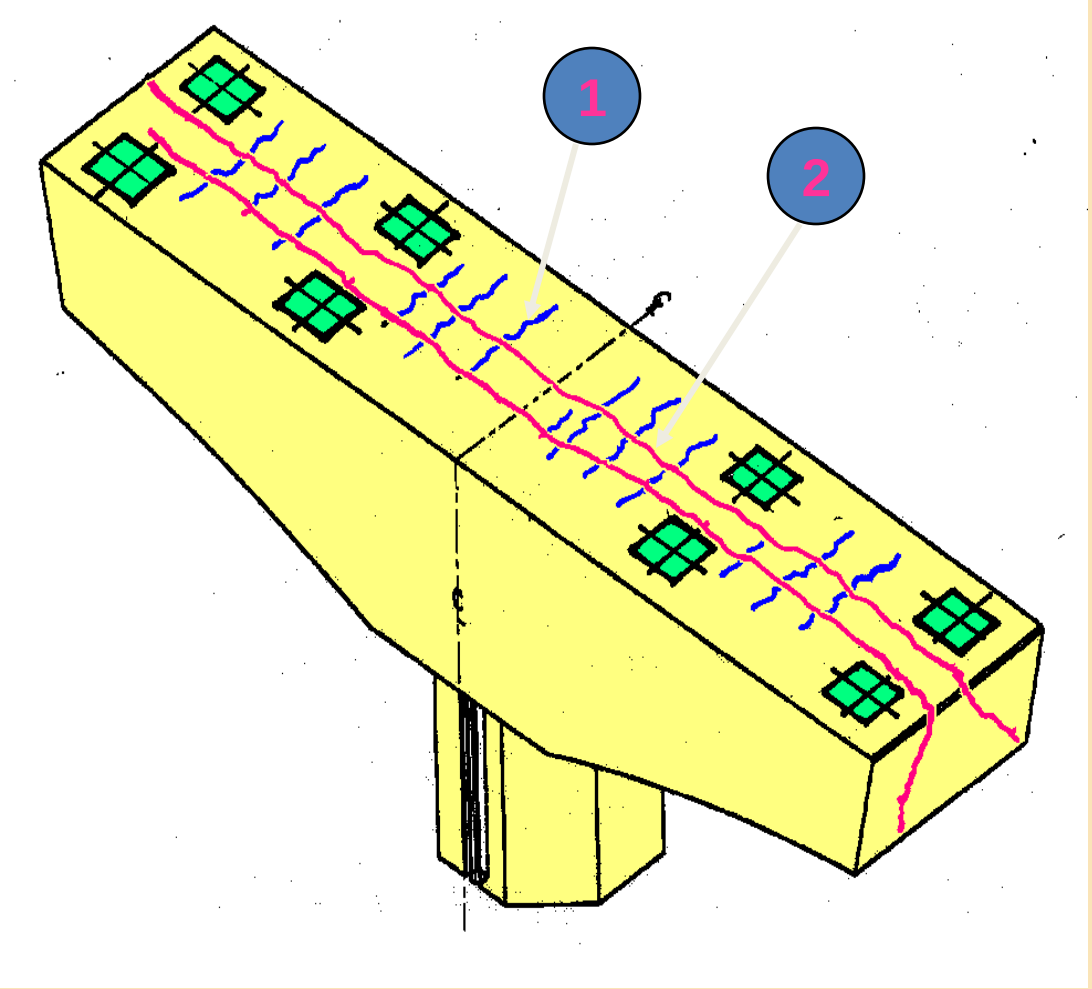
The Works Ministry had on Aug 9, 2004 ordered the 1.7km flyover to be closed to traffic after experts found it to be a threat to public safety.

Type 1 Cracking



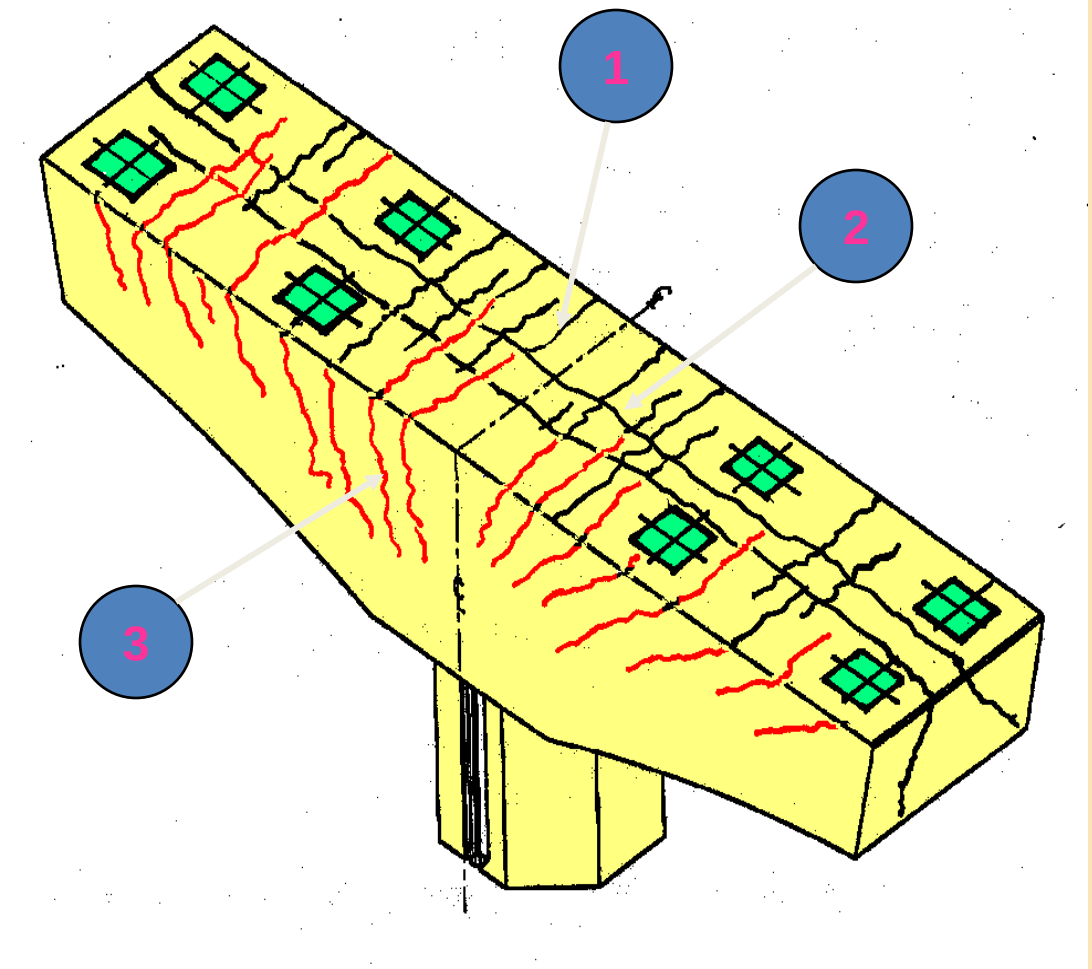
- Non-structural cracks due to early thermal expansion
- Occurred after striking of formwork
- Dead load due to self-weight only
- Insufficient curing and hence cracking is possible if the formwork was struck too early – no evidence to ascertain this

Type 2 Cracking



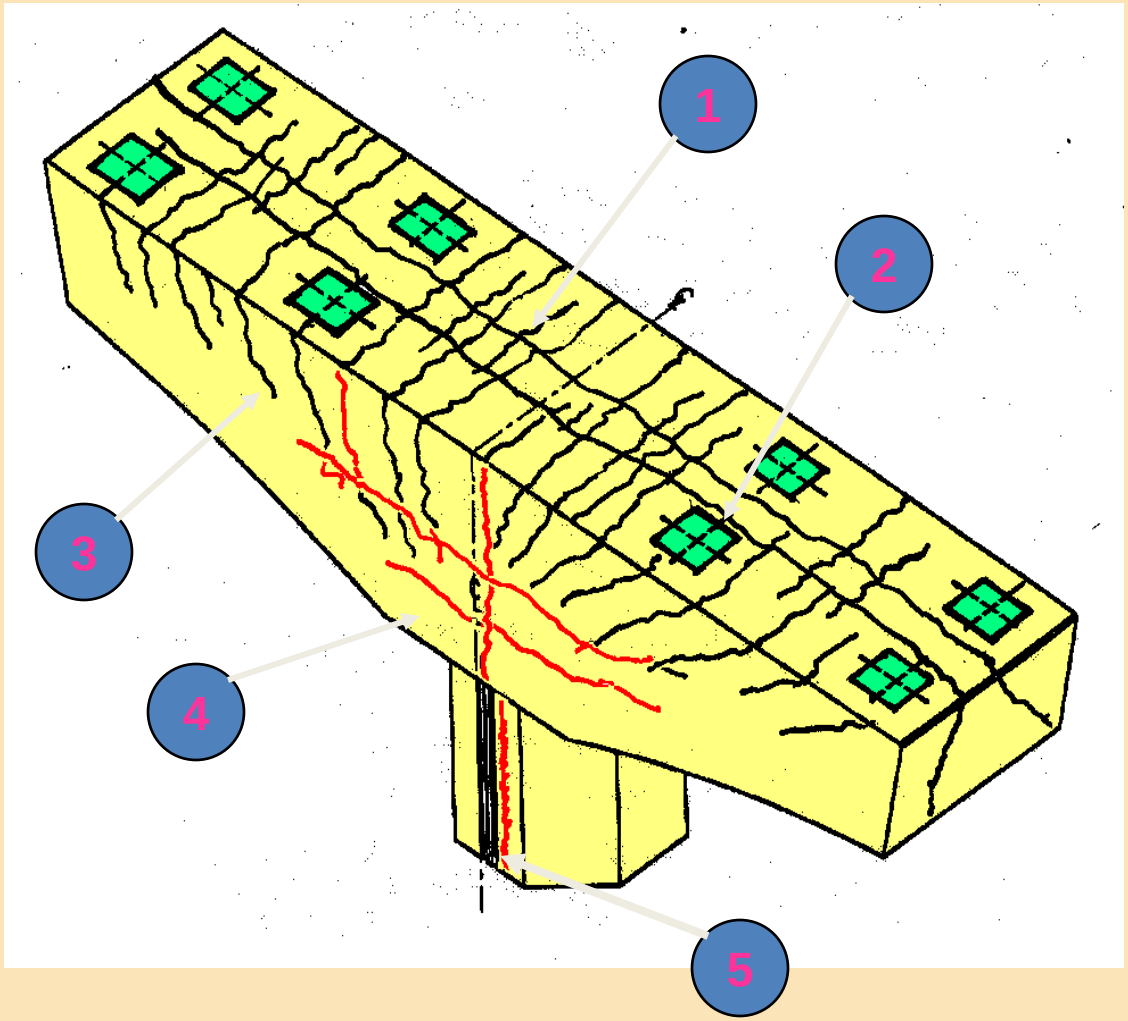
- Structural cracks – splitting of concrete.
- Inadequate transverse steel to take up tension.
- Cannot take up dead load (SW) plus crane during erection.
- No design calculations for transverse tensile force consideration.
- Factor of safety based on transverse tension is less than 1.

Type 3 Cracking



- Structural bending cracks due to reduced effective width and lack of bonding
- Bonding failure due to lack of bonding in lap at the mid-region of crosshead
- Cannot take up dead load plus crane load due to combined effect of bonding and splitting.
- Factor of safety for longitudinal moment is less than 1.

Type 4 & 5 Cracking



- Longitudinal cracks on the face of crosshead.
- New cracks propagated as the steel yielded.
- Vertical crack in pier stem initiated by tensile force at top of stem (see finite element modeling)

Deficiencies in Design

- Alternative design did not provide adequate transverse steel in the crosshead;
- Alternative design T16@175mm (replaced T20@150mm in the original design) was inadequate in resisting tension in the crosshead.
- This failure to take up transverse tension had caused splitting during erection of the box girders.
- The design calculations should have taken into account all loads including the crane loads during erection.
- The calculations for transverse steel in the alternative design and the consultant's assessment of the cracks were grossly missing.

Deficiencies in Detailing

- Location of lap for longitudinal bars in the mid-region of crosshead was not appropriate as it caused congestion of reinforcement – spacing of about 50mm between bars could not provide sufficient concrete for bonding.
- This had caused bonding failure even when the material quality and strength was adequate.
- Details in original design provided sufficient spacing between longitudinal steel (120mm) and there was no lap in the middle region of crosshead.

Procedural & Contractual

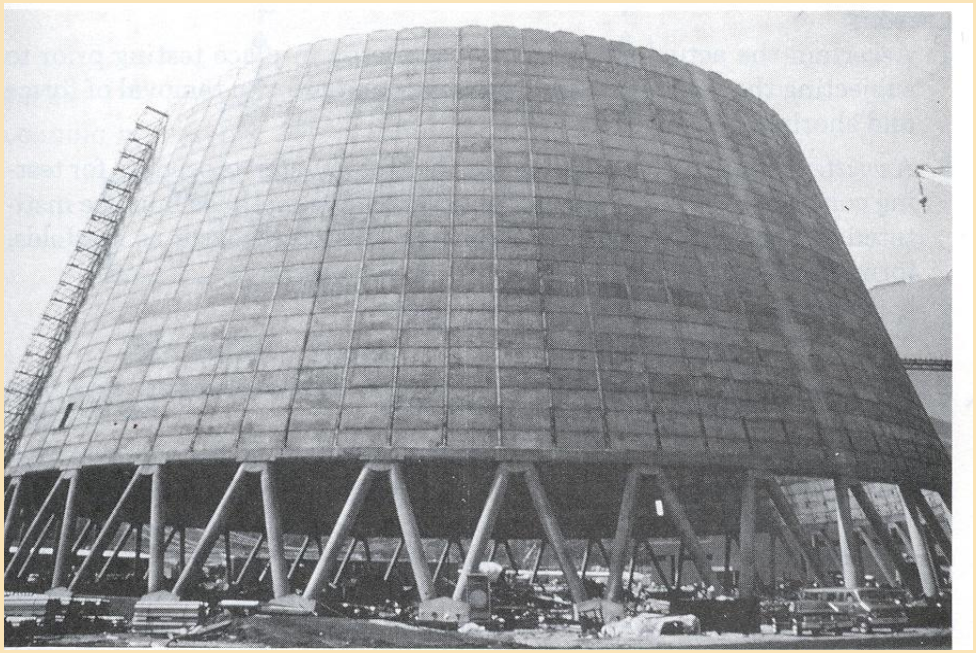
- Procedures to be adhered in the management of a design and build procurement system by both parties were more akin to those in a conventional procurement system, thus ‘best practices’ were not utilized.
- Although contractual matters pertaining to payment are clear and definite, it is against the normal procedures or usual practices in certifying work done. Coupled with the uneven risks distribution, the client’s interest was compromised at all times during the construction period.

Forensic Engineering Case Study 2:

Willow Island Cooling Tower Collapse During Construction

Willow Island
Cooling Tower Collapse (USA)

Collapse occurred on April 27, 1978, 10:00 a.m. Top portion of the concrete shell collapsed inward. Scaffolding and working platforms also collapsed. All 51 workers were killed.



Failure Investigation

- On-Site Investigation
  - Interviews; Laboratory Tests; Computer Analyses
- Inadequate Strength of Lift 28 on Concrete Shell to resist Construction Loads
- Sanctions
  - Tower Designer-Contractor
  - General Contractor
  - Testing Laboratories
- Legal Actions
  - Civil Suits & Criminal Charges

Forensic Engineering Case Study 3:

2000 Commonwealth Avenue Building Collapse During Construction

Collapse of Commonwealth Avenue Building Boston

The collapse of 17-story concrete high-rise under construction at 2000 Commonwealth Avenue, Boston, occurred on January 25, 1971. Many factors contributed to the collapse and can be seen in 3 phases:

- Phase 1: Punching Shear Failure in the Main Roof at Column E5
- Phase 2: Collapse of Roof Slab
- Phase 3: General Collapse

Phase 1: Punching Shear Failure

- About 3:00pm workers take break from placing concrete for the mechanical room floor slab
- Placement started at the west edge and proceeded east
- Shortly after break there was a drop in the floor slab
- Punching shear was noticed around column E5

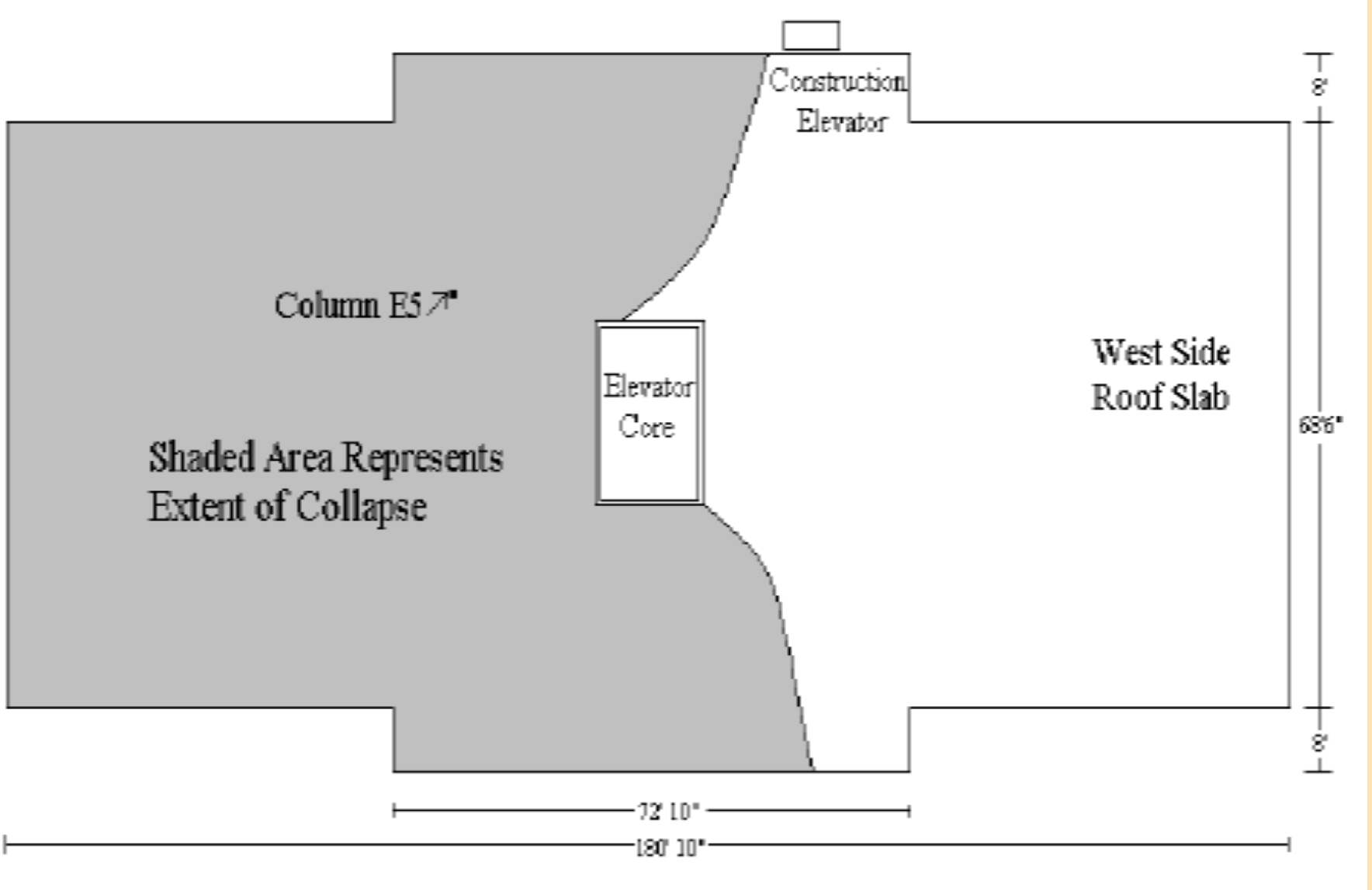
Phase 2: Collapse of Roof Slab

- After hearing a warning, most workers managed to get out of the way
- Roof slab began to form the shape of a belly
- Roof collapsed onto sixteenth floor
- At time, reinforcing steel was being placed, so workers were forced to cross over to the west side of the building

Phase 3: General Collapse

- Progressive collapse occurred 20 minutes after roof collapsed;
- Weight of the roof caused the 16 th floor to collapse onto 15 th and so on down to the ground 16th 15^{th};
- Two thirds of the building was gone ;
- Four workers died.

Extent of Collapse



Failure Hypothesis

Causes of Punching Shear related Failure

- Concrete strength was well below required 3000 psi
- Inadequate shoring under the roof slab
- Construction equipment and two boilers were on the roof

Failure due to Design Flaws

- Insufficient length of rebar: the bars did not extend enough into columns
- Incorrect placement of bars: confusion with deliveries; design around columns did not meet ACI codes

Failure Related to Procedural/Construction Flaws

- Lack of proper building permit and field inspection
- Premature removal of formwork
- Lack of construction control

Conclusions

- Forensic engineering is the application of engineering sciences to the investigation of failures or other performance problems.
- A wide and multi-disciplinary field, requiring engineering expertise and knowledge of legal procedures.
- Forensic engineering deals with the investigation and re-construction of failures in buildings, bridges, facilities, vehicles and other engineered systems.
- Engineers & managers need to have a helicopter view of the process, techniques, outcome reporting and legal aspects of forensic engineering investigation.

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Terima Kasih