EG0001

Engineers & Society

Case Studies in Engineering Ethics

Adapted from Prof Lim Mong King (2016)

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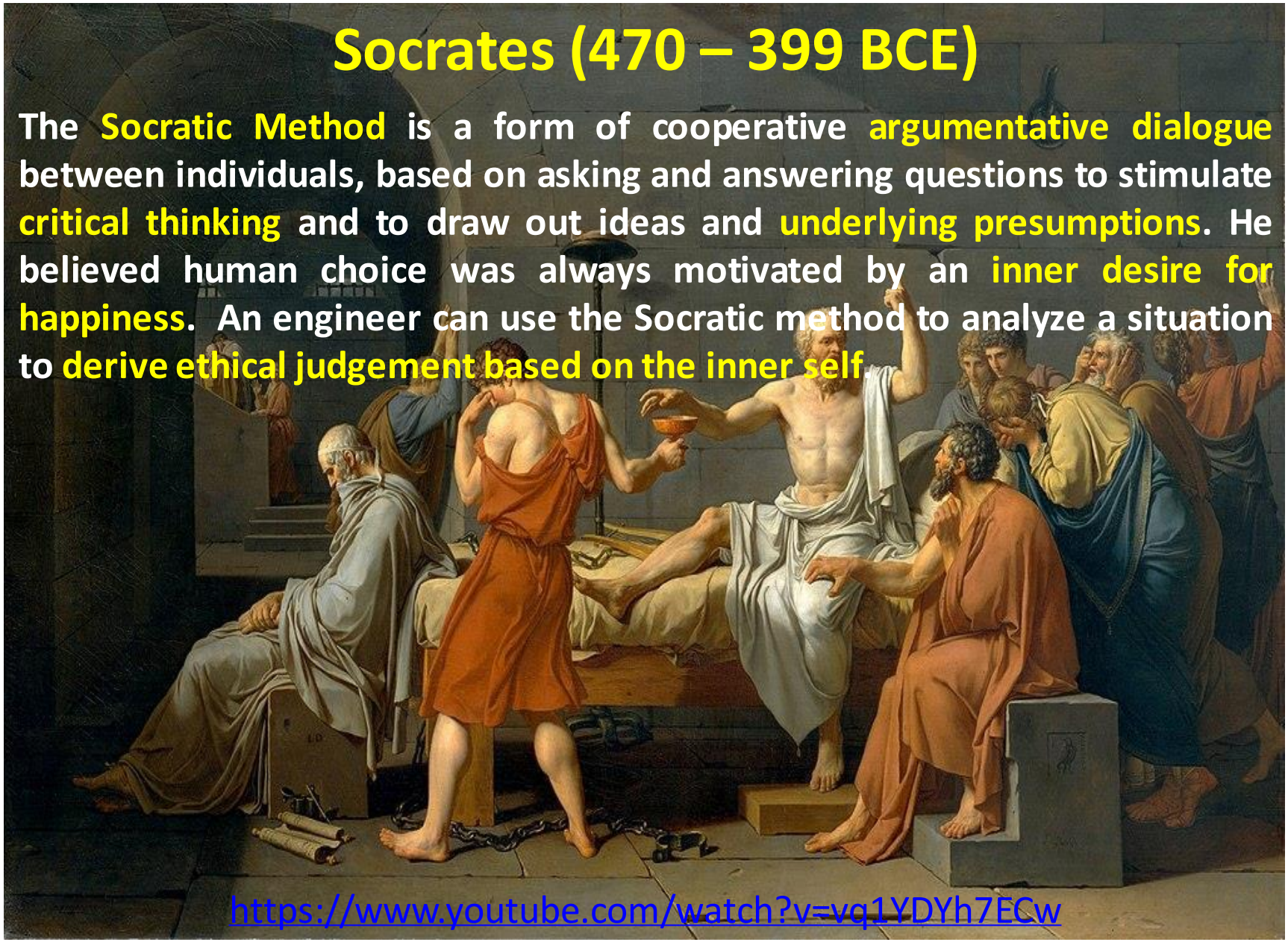
Socrates (470 – 399 BCE)

The **Socratic Method** is a form of cooperative **argumentative dialogue** between individuals, based on asking and answering questions to stimulate **critical thinking** and to draw out ideas and **underlying presumptions**. He believed human choice was always motivated by an **inner desire for happiness**. An engineer can use the Socratic method to analyze a situation to **derive ethical judgement based on the inner self**.



https://www.youtube.com/watch?v=vq1YDYh7ECw

By Jacques-Louis David - http://www.metmuseum.org/collection/the-collection-online/search/436105, Public Domain, https://commons.wikimedia.org/w/index.php?curid=28552

Crito - *The dialogue takes place in Socrates' prison cell.*

His old friend *Crito*, had made arrangements to smuggle Socrates out of prison.

- **Socrates seems willing to await his imminent execution.**
- **Crito presents many arguments to persuade Socrates to escape.**
- **Socrates' death will reflect badly on his friends.**
- **Socrates need not worry about the risk or the financial cost.**
- **On a more ethical level, Crito presents two pressing arguments:**

1. If he stayed, he would be aiding his enemies in wronging him unjustly, and would thus be acting unjustly himself
2. He would be abandoning his sons and leaving them without a father.

Socrates: *One should **not worry about public opinion**, but only listen to wise and expert advice*. Crito should not worry about how his, Socrates', or others' reputations may fare in the general esteem: **they should *only concern themselves with behaving well*. *The only question at hand is whether or not it would be just for Socrates to attempt an escape*.** If it is just, he will go with Crito, if it is unjust, he must remain in prison and face death.

Justify not to escape; Any justifications to escape?

At this point, Socrates introduces **the voice of the Laws of Athens**, which speaks to him and proceeds to explain **why it would be unjust for him to leave his cell**.

Since the **Laws exist as one entity**, to break one would be to break them all, and in doing so, **Socrates would cause them great harm**. The citizen is bound to the Laws like a child is bound to a parent, and so **to go against the Laws would be like striking a parent.**

Rather than simply break the Laws and escape, **Socrates should try to persuade the Laws to let him go.** These Laws present the citizen's duty to them in the form of a kind of **social contract**. By choosing to live in Athens, **a citizen is implicitly endorsing the Laws**, and is willing to abide by them. Socrates, more than most, should be **in accord with this contract**, as he has lived a happy seventy years fully content with the Athenian way of life.

If Socrates were to break from prison now, having ***so consistently validated the social contract,*** he would be making himself an **outlaw** who would not be welcome in any other civilized state for the rest of his life. And when he dies, he will be harshly judged in the underworld for behaving unjustly toward his city's laws. Thus, Socrates convinces Crito that it would ***be better not to attempt an escape.***

Crito said that Socrates would be ***unjustly joining the efforts of his enemies against him.*** He is choosing the "easiest path" as opposed to the courageous, honorable, and virtuous path, which Crito feels is to flee from certain, unjust death. Socrates would be acting with cowardice if he weren't to resist such injustices.

Crito further argues that a father (like Socrates) has an obligation to nurture and educate his children and should avoid orphaning them. He says that the failure to escape will be a ridiculous climax to the whole affair and ***would be attributed to the shameful cowardice of Socrates' friends.***

Socrates' responses

- Socrates tells Crito that he is one of those people who must be ***guided by reason***.
- Socrates was serious at his trial about not fearing death. He expresses contempt for the ***opinions of the masses*** of mankind who ***think irrationally and act randomly.***
- Socrates says that the only person whose opinion is of value is the ***one who understands justice.***
- Money, reputation and feeding children are ***values of thoughtless men***.
- The question is whether it would be unjust for Socrates to escape, not what people would think about him.
- Socrates argues that if it is never good to do injustice, *then* ***certainly it is never good to do injustice in response to injustice***.

This does not answer whether it is just or unjust for Socrates to escape from the prison, so Socrates **asks what the Laws would say about his leaving.** Socrates claims that the Laws would say that **he destroys the city in leaving, and that this would be unjust.** The Laws say that a citizen stands in relation to the city as the child does to the parent, as **the slave does to his master.**

The Laws would further say, Socrates says, **that he entered into a contract with them by remaining within the city, benefiting from it, and so now cannot justly attack it on account of having been unjustly convicted**. Socrates says the laws argue that **he tacitly agreed to obey the law by remaining in Athens** after having reached maturity, witnessing the structure of the law and how it functions, and raising children of his own in Athens.

Socrates does not declare that he is satisfied with the Laws' argument, instead asking Crito whether they mustn't accept it. **Crito says they must,** and so the dialogue comes to a conclusion

Thus, no justification to escape?

The Socratic Method works to clarify a person's own beliefs by:

- Evaluating their worth 
- Clarifying the concepts of good and justice. 

"A person can find the answer to any problem by breaking it down into a series of questions and then finding the answers."

Socrates was not convinced that achieving practical results through theological doctrine is sufficient for society. **He wanted an ethical system derived from the inner self.** He believed human choice was always motivated by an inner desire for happiness.

"The ultimate wisdom would come to a person who knew themselves because the greater the person's ability to reason, the better the person's ability to make choices that would bring about great happiness." 

Recent Case:

Hutton Report (Jan 2004) on Death of Dr David Kelly. Both, Chairman and Director of BBC resigned saying "We resign although we do not agree with the findings in report, but we accept the verdict because we had agreed to the appointment of Lord Hutton in the inquiry".

Kwame Anthony Appiah – *Morality concerns only one's relationship to others whereas ethics is about what it means for a person to live a good life in a wider sense.*

Julian Baggini – *Morality is about the action we need to do or to avoid, the rules to follow in order to do right by other people,* ***whereas ethics is what we need to do in order to flourish ourselves.***

Adam Smith – *There is evidently some principles in man's nature, which interest him in the fortune of others, and render their happiness necessary to him, though he derives nothing from it except the pleasure of seeing it.*

David Hume – *Reason is and only ought to be the slave of the passion. (Reason alone could never tell what you ought to do. Ultimately, ethics does boil down to a judgement.)*

Case Studies

- Engineering ethics is often times best explained through the use of case studies.
- Case studies allow examples of good and bad decision making in a real world context.
- **Oppenheimer's Dilemma (Father of the Atomic Bomb):**
  - ✓ On July 1945, the first-ever atomic bomb was detonated and in Aug 1945 two atomic bombs were dropped on Hiroshima and Nagasaki, which ultimately pushed the Japanese to surrender ***(bombing was morally justified by him based on relative cost of human lives).***
  - ✓ Instead, he felt responsible for the **ensuing arms race and threat to civilization** ***(danger of proliferation)*** brought about by the bomb.
  - ✓ Due to his complex moral code, **he objected to the development of the H-bomb** ***(social and political consequences)***.
  - ✓ **Will the bomb be the bringer of LIFE** through nuclear power and sustainable energy, or **will Oppenheimer in DEATH** ultimately become the destroyer of our world.

Ethical Decision needs to consider the consequences!

https://www.youtube.com/watch?v=pzA88OTdwR0

USA National Society of Professional Engineers NSPE Code of Ethics

- **Fundamental principles**
  1. **Hold paramount the safety, health and welfare of public**
  2. Perform services in area of competency
  3. Issue public statement in an objective and truthful manner
  4. Act for employer or client as a faithful agent and trustees
  5. Avoid deceptive acts
  6. Conduct themselves honorably, responsibly and lawfully so as to enhance honor, reputation and usefulness of the profession

Based upon these fundamental principles, various engineering societies develop their own (usually more specific) codes of ethics

For each example, the case is presented, the ethical questions and debates are stated, then the NSPE's ruling on the case is listed. 

Develop the abilities necessary to engage in constructive ethical analysis.

Stimulate the moral imagination by challenging us to anticipate the possible alternatives in solving them and the consequences of those alternatives.

Through cases we learn to recognize the presence of ethical problems and to **develop the analytical skills** needed to resolve them.

Show that **code cannot provide ready-made answers** and individual must become a responsible moral agent.

There may be **irresolvable uncertainties** in ethical analysis and there may be **disagreement about what is right**.

Case A: The Disaster at Bhopal
The Plant Background

- Manufactured pesticide in India
- Part of India's Green Revolution
- To increase the productivity of crops
  - Plant initially welcomed at Bhopal for its economic potential
  - Located 2 miles from city center; **surrounding population expanded significantly after construction**.
  - Government classified plant as **"general" (not "hazardous")** industry in 1976, even after approving **MIC-based processes** at plant and establishing a "hazardous industry" zone 15 miles from city

Case A: The Disaster at Bhopal
Why Was Bhopal Chosen?

It's central location in India

A railway system that spanned the country

A large lake which provided a reliable source of water

Sufficient electricity and labor to sustain a large scale industrial plant

Union Carbide's Bhopal Plant

adjacent to an existing residential neighbourhood

Case A: The Disaster at Bhopal

- **December 2, 1984 a leak developed in a storage tank at a Union Carbide chemical plant in Bhopal, India.**

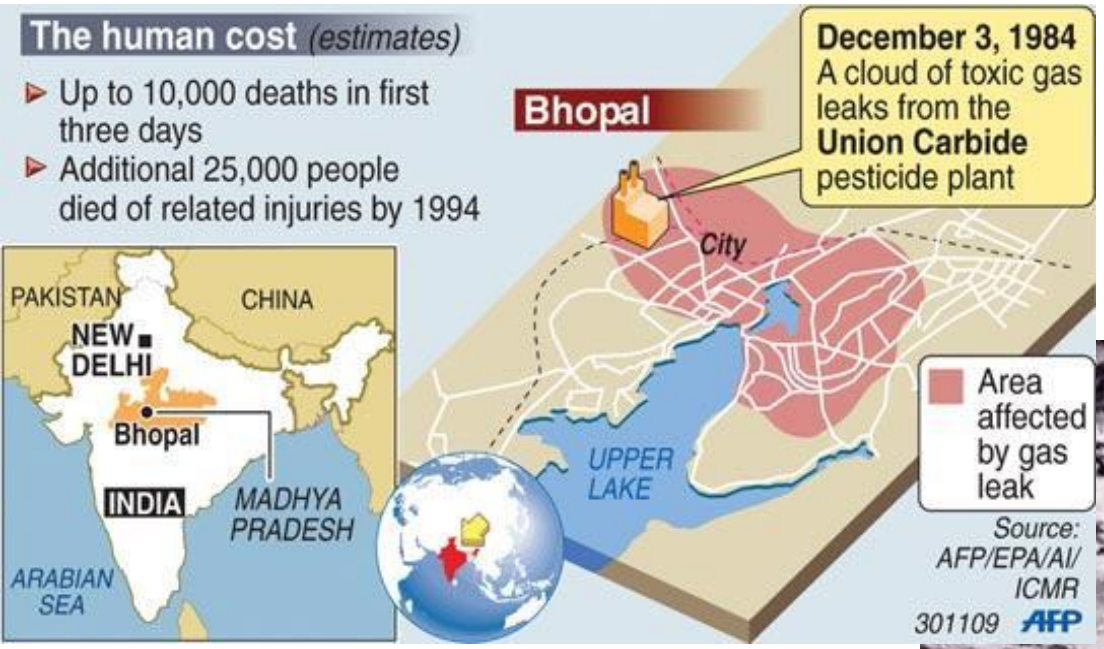
- Tank contained **10,000 gallons of MIC** (methyl isocyanide).

- The leak sent a **toxic cloud of gas** over the surrounding slums of Bhopal, resulting in the **death of over 10,000 people and injuries over 200,000 more.**

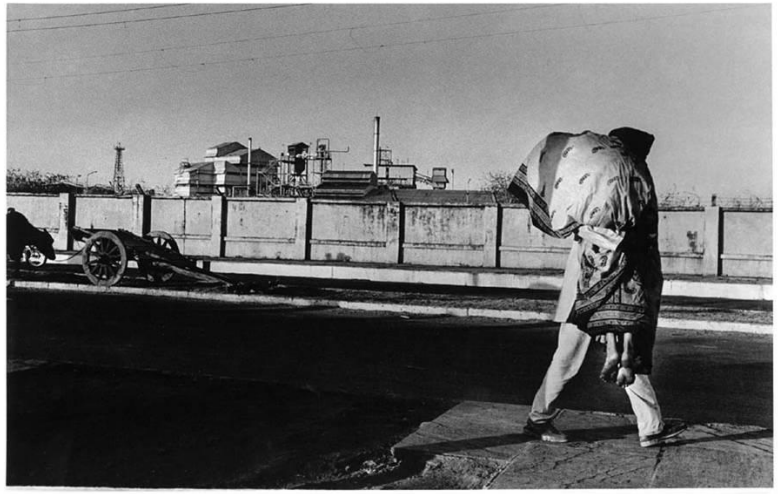
https://www.youtube.com/watch?v=e0c0w8aw8Yk

Case A: The Disaster at Bhopal
Impacts

Up to 10,000 deaths in the first three days of the gas leaks.

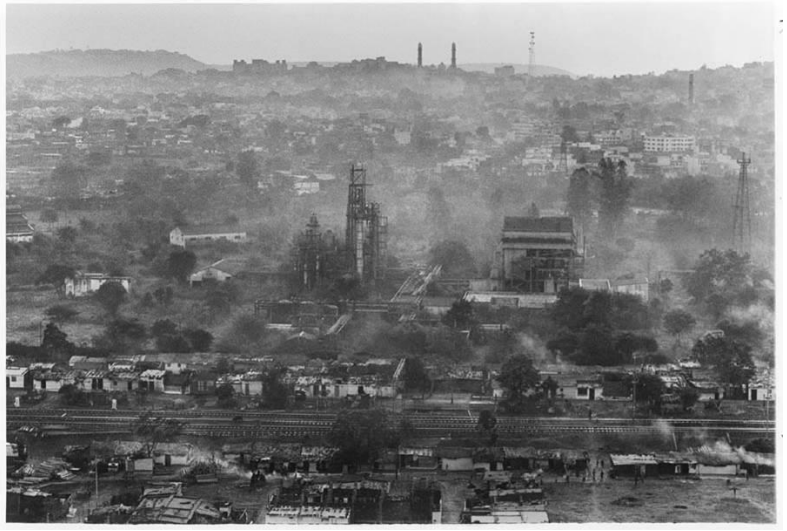


Case A: The Disaster at Bhopal



Credit: AP/World Wide Photos

1984: Death cloud sweeps Bhopal, India.



Case A: The Disaster at Bhopal
Cause of Leakage

- The leak was attributed to the **leakage of water** (valve not properly closed) **into the MIC storage tank during maintenance**. Water reacts very vigorously with MIC, **causing heating of the liquid.**

- Mixing of water with MIC increased the temperature of the liquid in the tank to **400^0F causing MIC to vaporize**, leading to a build-up of **high pressure** within the tank.

- When internal pressure became high enough, **a pressure-relief valve opened, leaking MIC vapored into the air.**

Case A: The Disaster at Bhopal
Root Cause of the Incident

- As many of the disasters and accidents **there was not just one event that led to the disaster**, **but rather there were several factors.**

- A major factor in this accident was the **curtailment of plant maintenance** as part of a cost-cutting effort.

Case A: The Disaster at Bhopal

1. The MIC storage tank had a **refrigeration unit** on it, which should have helped to keep the tank temperatures closer to normal. However, this had **stopped working five months before the accident and hadn't yet been repaired**.

2. The tank was equipped with a **alarm** that should have alerted plant workers to the dangerous temperatures: this alarm was improperly set, **so no warning was given.**

What are the several factors?

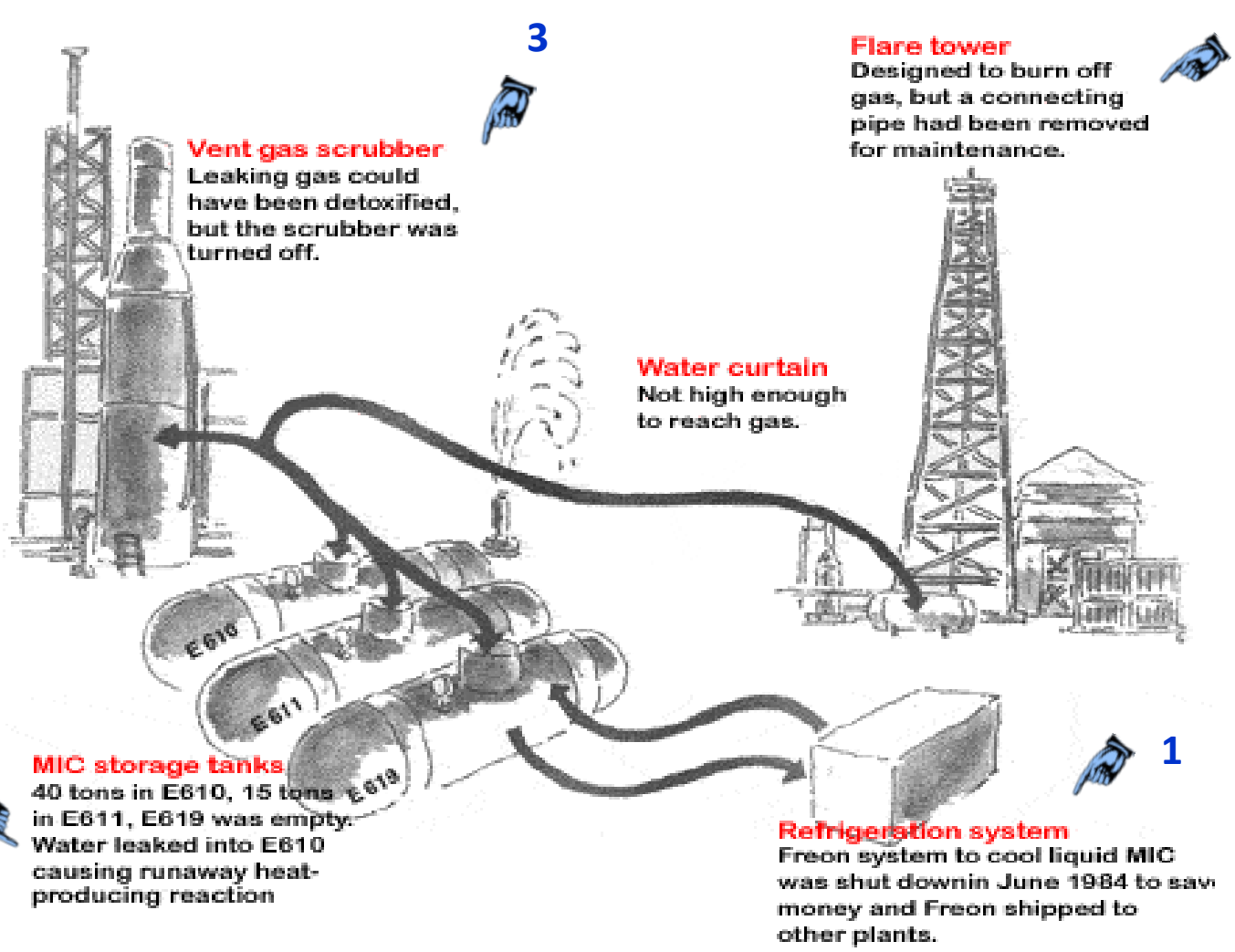
Case A: The Disaster at Bhopal

3. The plant was equipped with a **flare tower, which was designed to burn vapours** before they enter atmosphere, and would have been able to reduce, if not eliminate, the amount of damage. The **flare was not functioning**.

4. Finally, a **scrubber** that was used to neutralize toxic vapours **was not activated** until the vapour release was already in progress.

Leakage of water → non-working of refrigeration unit → wrong setting of warning alarm → malfunctioning of flare tower → non-activation of scrubber

Case A: The Disaster at Bhopal
How did this incident occur?



Case A: The Disaster at Bhopal
How did this incident occur?

Causes	Reasons
Temperature alarm	**Not properly set**
Refrigeration system	Disabled **Cost saving**
MIC storage content level	Did not follow the recommended value **Disregarded safety**
Vent gas scrubber	Small scale accident design, not activated automatically **Cost saving**
Flare tower	Small scale accident Design Not functioning **Cost saving**
Water curtain spray	Small scale accident design **Cost saving**

- Profit driven
- Place more importance in cost saving over safety
- Poor safety measures
- **Emphasis on safety**
- **Follow and maintained**
- **Mitigated the severity of consequences**

Case A: The Disaster at Bhopal
Who is Responsible ?

- The plant designers clearly did their job, although with some safety features under design. **But:**

  - **The management of the plant seems obviously negligent.**

  - **Union Carbide also seems negligent in not preparing a plan for notifying and evacuating the surrounding population in the event of an accident.**

Case A: The Disaster at Bhopal
Who is Responsible ?

- Indian government is also blamed not to put on some safety standards.
- Local government had no policy or zoning forbidding squatters and others from living so close to a chemical plant.
- **The bulk of the blame goes to UC for failure to adequately train and supervise its Indian employers in the maintenance and safety procedures that are taken for granted.**

Case A: The Disaster at Bhopal
Consequences

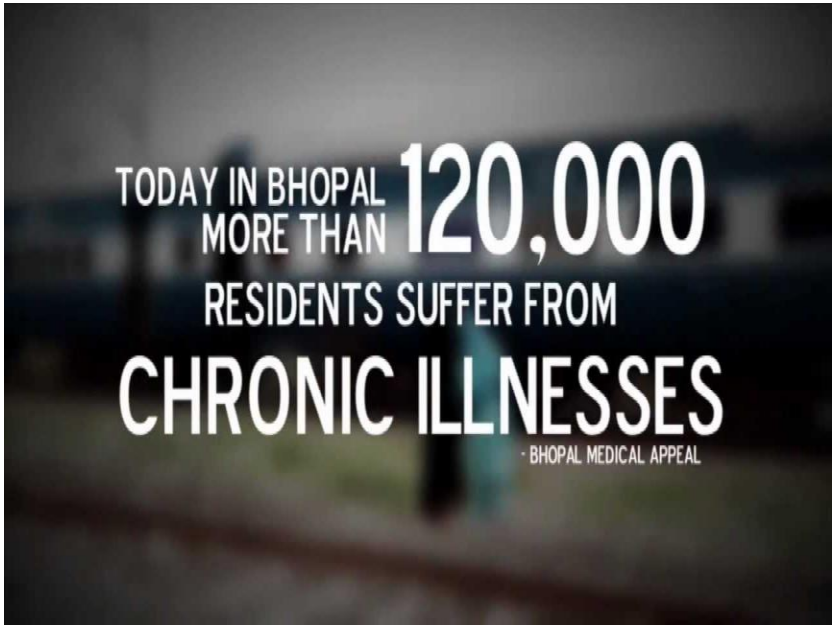
- Resulting in the death of over 10,000 people and injuries over 200,000 more.
- UC paid over $250 billion for the lawsuits on behalf of the victims of the accident.
- UC also helped set up job training and relocation programs for the victims of the accident.
- Ultimately, it has been estimated that approximately 10,000 of those injured in the accident will suffer some form of permanent damage.

Case A: The Disaster at Bhopal
Lesson Learnt

- This case in engineering ethics shows us the importance of the **safety of the workers and the environment no matter where the place is**.

- In order for a project to be completed successfully, cooperation among team members is essential.

30 years later…

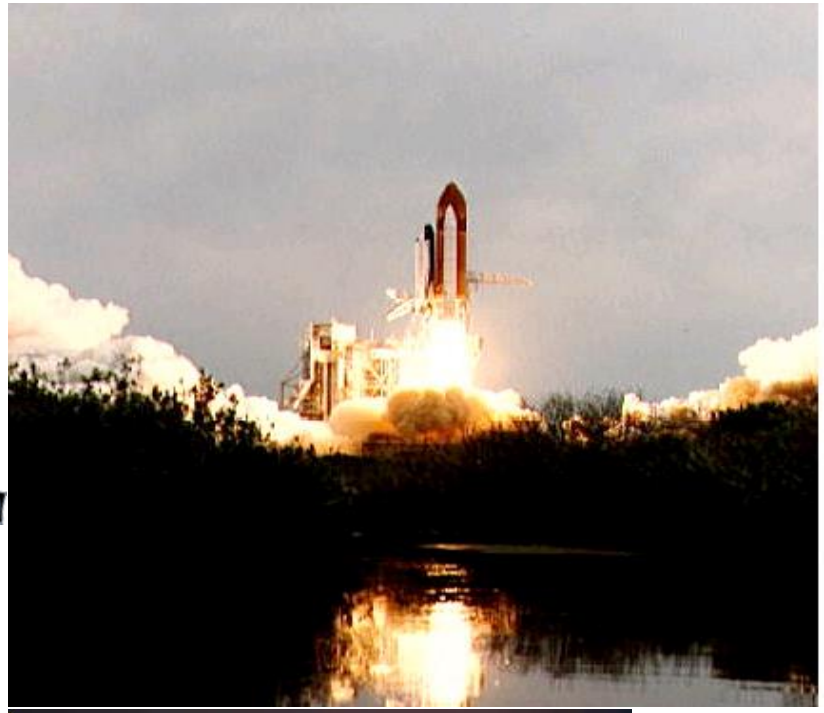


HAUNTING IMAGES OF THOSE WHO RELIVE THE TRAGEDY DAILY: Rupesh, Adil, Shanu - Some survivors of the Bhopal gas tragedy

The plant site has not been cleaned. It has been left as it was…

Case B: The Challenger Disaster

- January 28, 1986, seven astronauts were killed while piloting the Challenger space shuttle.
- Challenger exploded seconds after take off due to failure of rocket booster O-rings.
- Failure of O-ring due to several factors, faulty design, lack of testing in low temperatures, and etc.

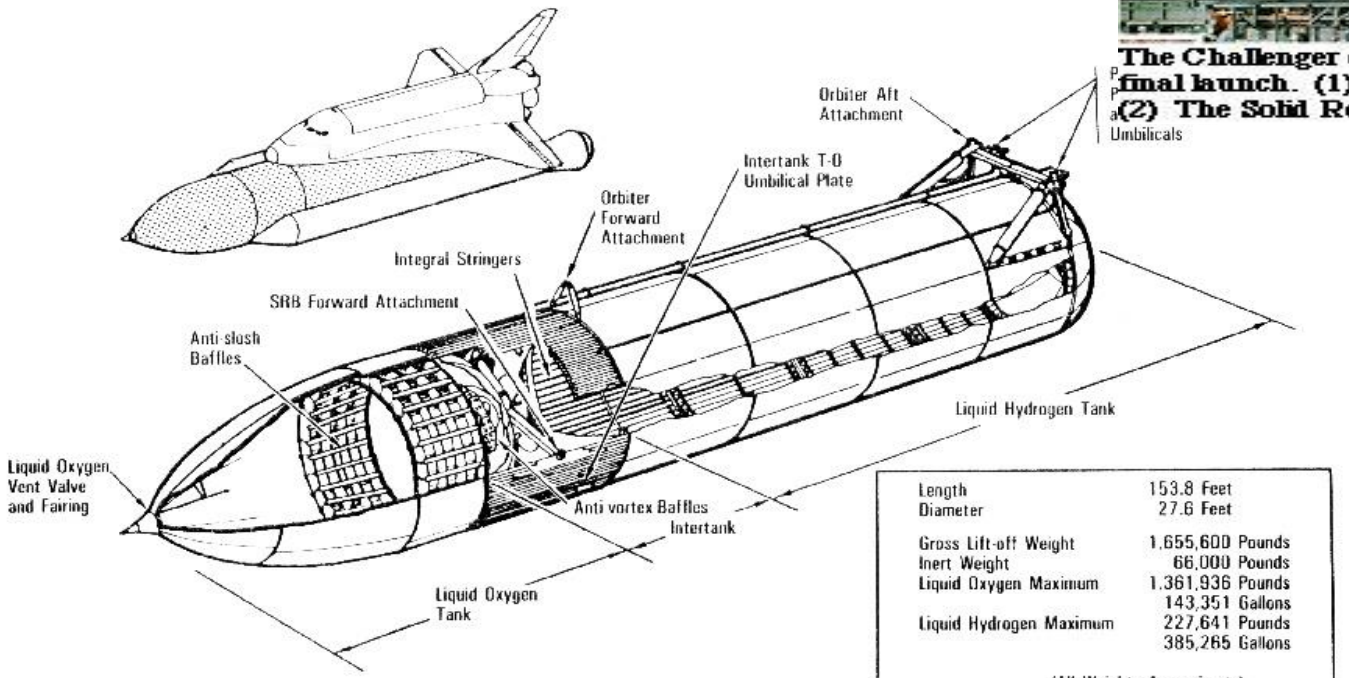


Shuttle Components

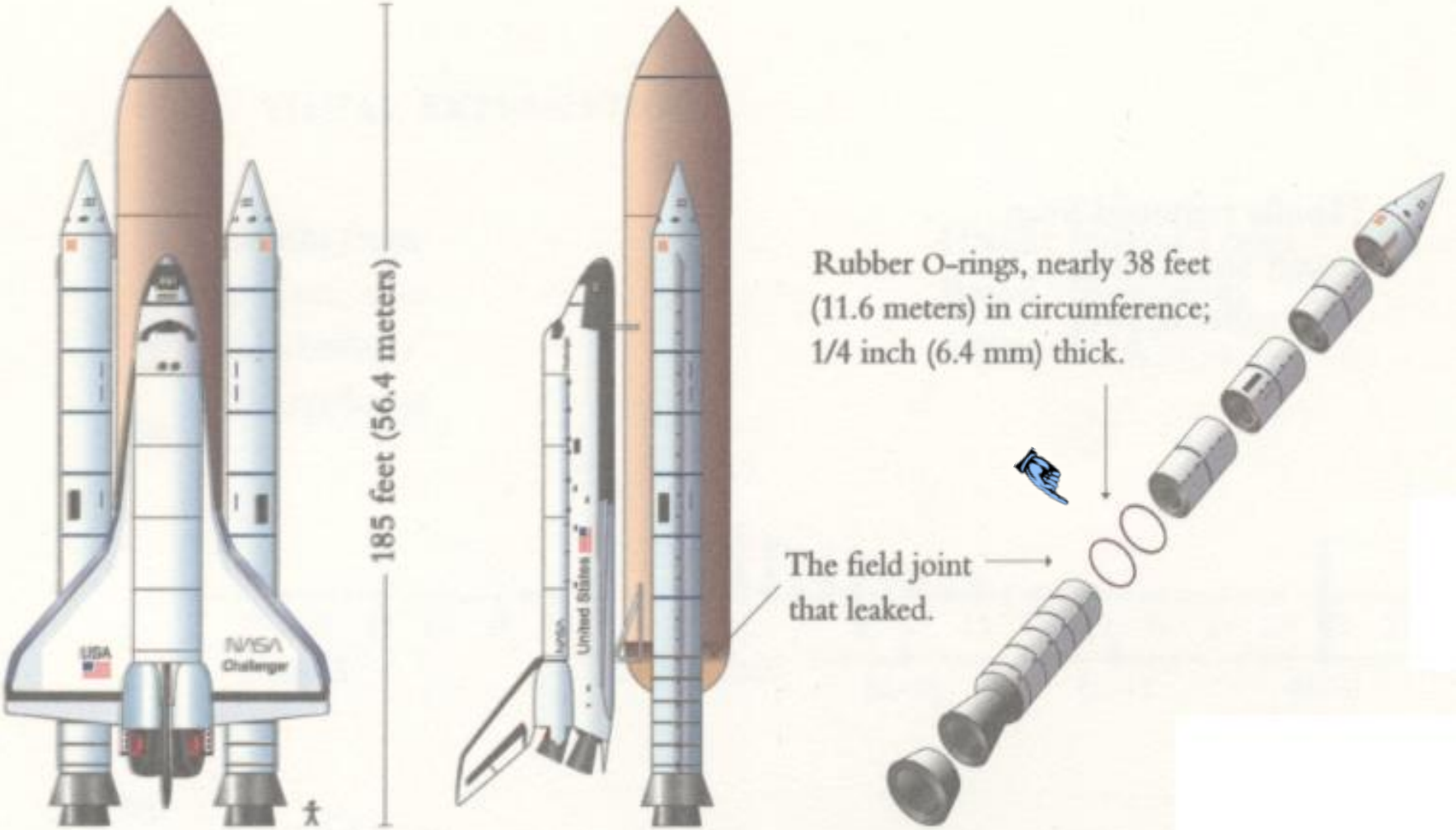
1. Liquid Rocket Booster
2. Solid Rocket Booster
3. Orbiter

Presidential Commission Report, p. 112

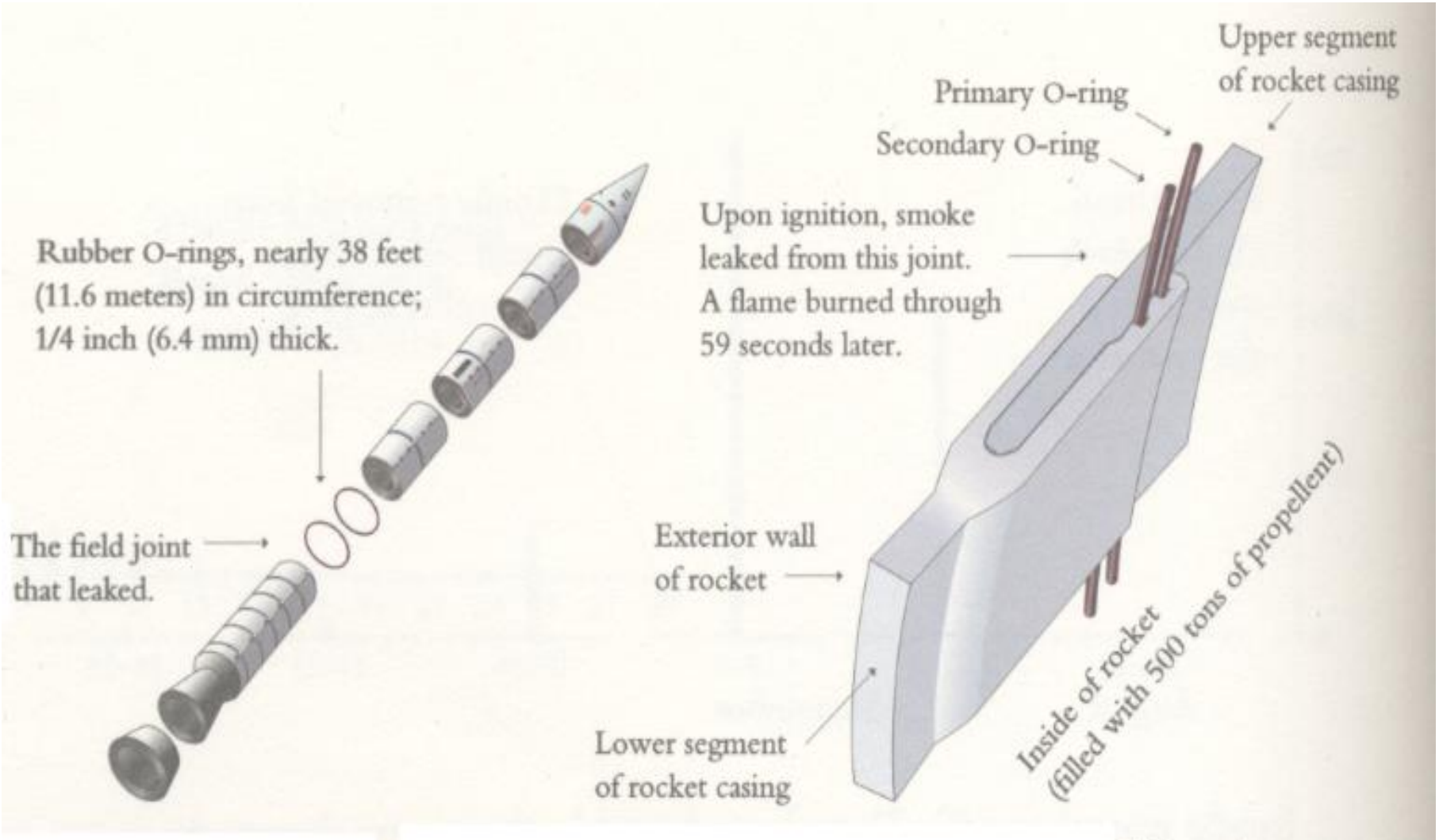
The Challenger on the morning of its final launch. (1) The External Tank. (2) The Solid Rocket Boosters.



Lightweight External Tank

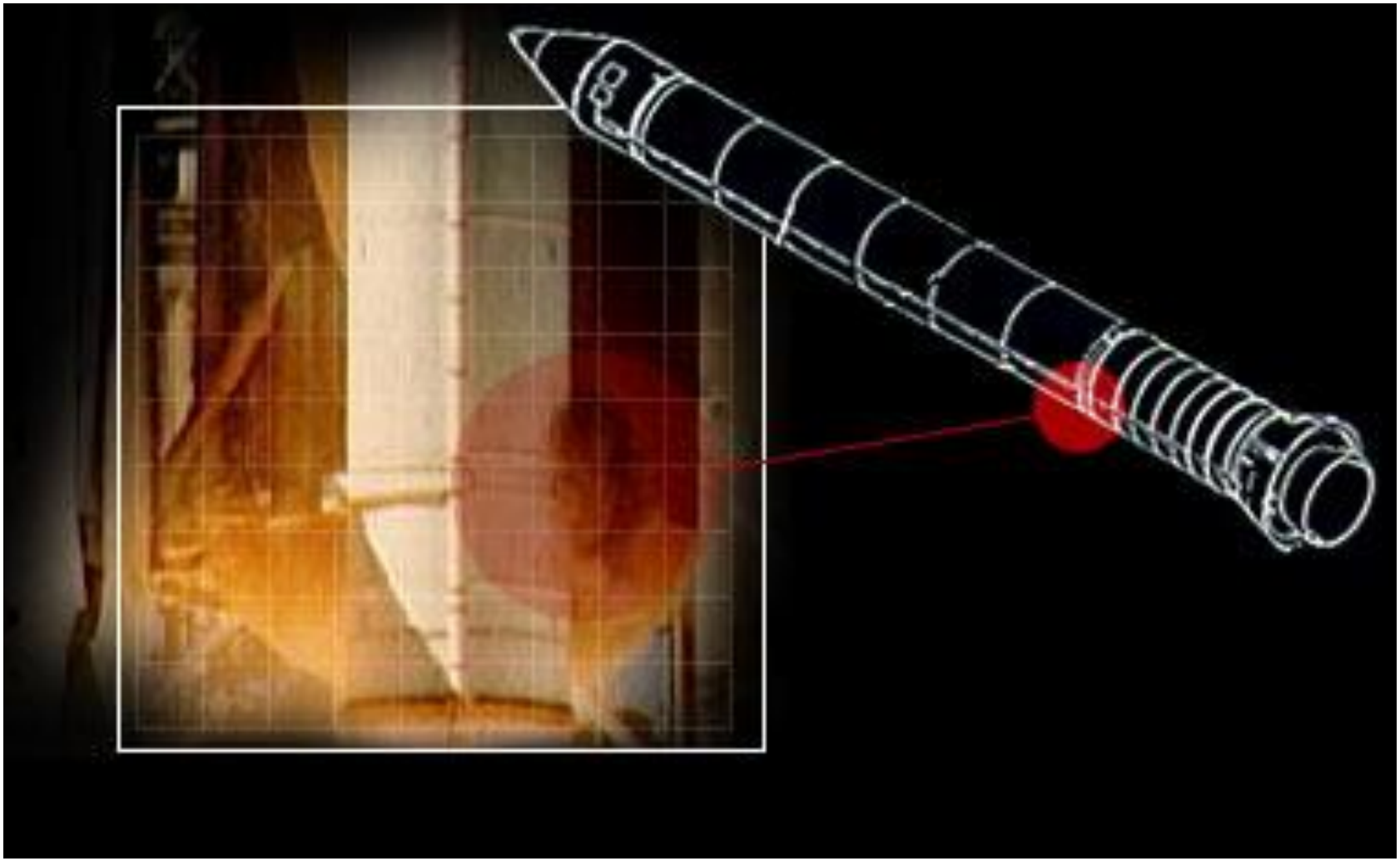


The shuttle consists of an *orbiter* (which carries the crew and has powerful engines in the back), a large liquid-fuel *tank* for the orbiter engines, and 2 solid-fuel *booster rockets* mounted on the sides of the central tank.

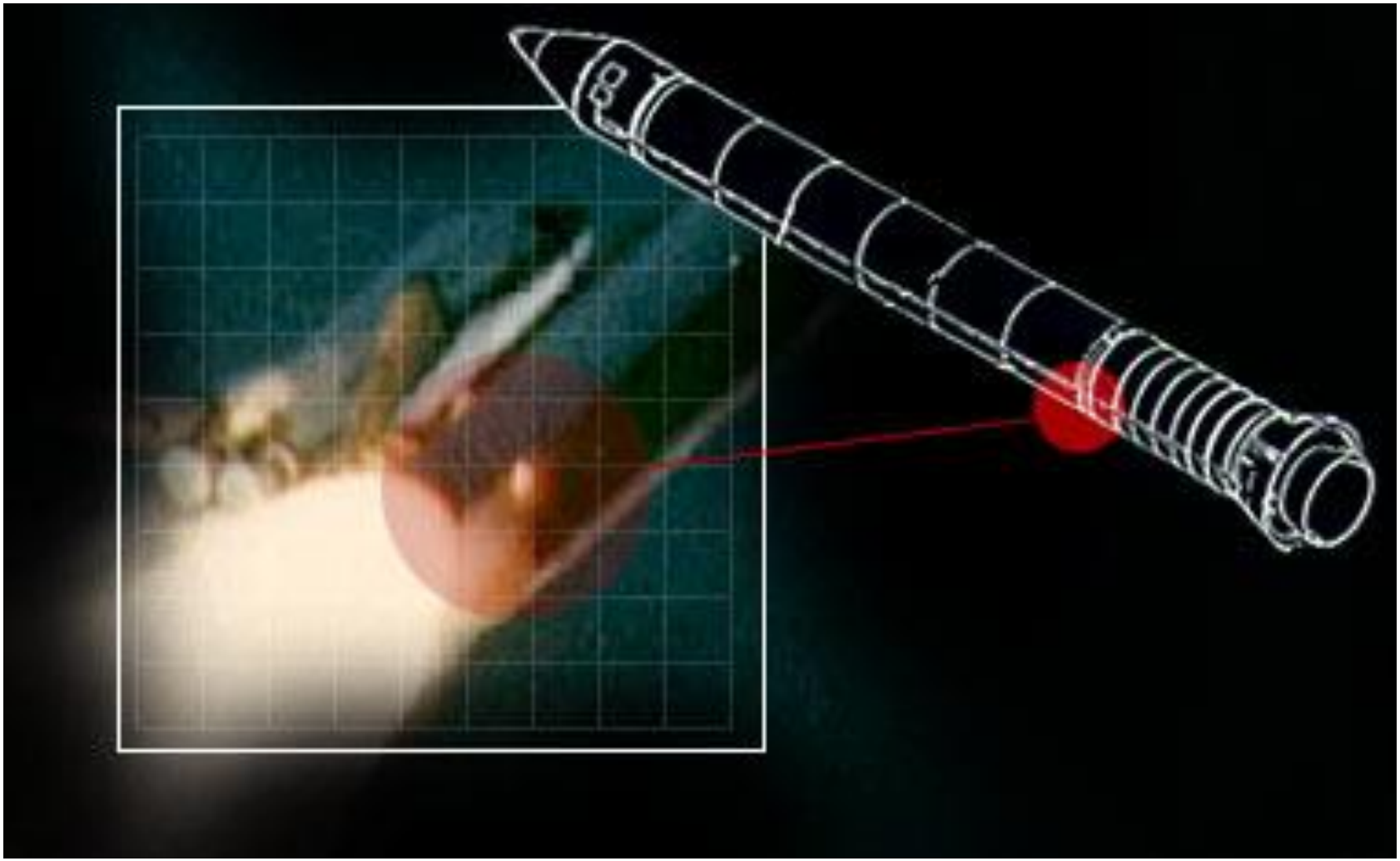


Where these segments mate, each joint is sealed by two rubber O-rings as shown above. In the case of the Challenger accident, one of these joints leaked, and a torch-like flame burned through the side of the booster rocket.

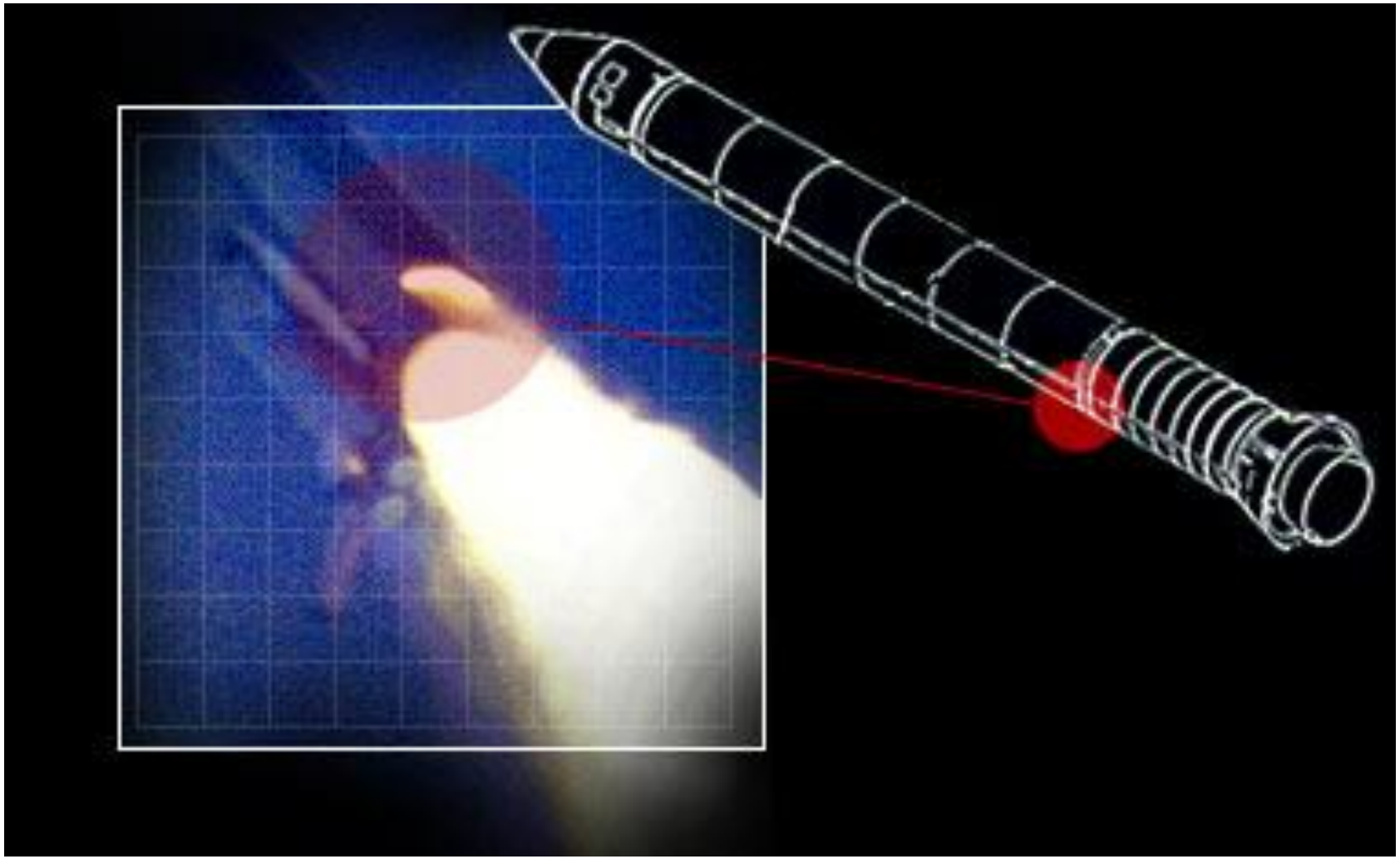
3 Seconds



59 Seconds



64.7 Seconds



73 seconds

As the shuttle exploded and broke up at approximately 73 seconds after launch, the two booster rockets crisscrossed and continued flying wildly. The right booster, identifiable by its failure plume, is now to the left of its non-defective counterpart.

Case B: The Challenger Disaster

https://www.youtube.com/watch?v=j4JOjcDFtBE

Case B: The Challenger Disaster

- Space shuttle *Challenger* was designed to be reusable launch vehicle.
- A key aspect of the booster design are the joints where the individual cylinders come together.
- **The joints are sealed by two O-rings.** The O-rings which are made from synthetic rubber are designed to prevent hot gases from the combustion of the solid propellant from escaping.
- **Previously the O-rings were found to be inadequate and redesigned causing delays in the program.**

Case B: The Challenger Disaster

The political climate: 

- NASA budget was determined by Congress who was **unhappy with the delays** of the shuttle.
- European Space Agency was developing what seemed to be a **cheaper alternative** to the shuttle.
- NASA felt pressure to get the *Challenger* launched on time so that the next shuttle launch was to carry a probe to examine Halley's comet **before Russians launch**.
- President Reagan was planning to mention the shuttle and a special astronaut - **the first teacher in the space** - Christa McAuliffe before the upcoming state-of-the-union address.

Socratic Method: one should **not** be concerned about these issues! One should make decision based on safety, health and welfare to derive an ethical judgement fulfilling his inner-self happiness.

Case B: The Challenger Disaster

The days before the launch

- The first launch date was postponed due to cold front expected to move through the area.

- Again another **cold front** was expected with temperatures predicted to be in the low 20's (^{o}F) by the new launch time.

Case B: The Challenger Disaster

Night before the launch

- **14 engineers at Morton Thiokol** had unanimously and **vigorously voiced opposition to the launch.** Boisjoly and others: "too cold, delay launch! Until 53ºF".

- They warned that temperatures at the launch site were below the tested safety range. Low temperatures could make O-rings, which form part of the seals between segments of the booster rockets, less pliable and cause them to fail.

- Moreover engineers were **aware of a history of concern** over these seals, which had shown alarming erosion in previous launches and were already being redesigned.

Case B: The Challenger Disaster

- During the teleconference, Roger Boisjoly and Arnie Thompson, two Thiokol engineers who had worked on the solid-propellant booster design, gave an hour-long presentation on how the cold whether would increase the problems of joint rotation and sealing of the joint by the O-rings.
- However, they did not have enough verified experimental data.
- After discussion with **Jerald Mason (General Manager), Bob Lund (Vice President) gets the engineers to accept a launch recommendation.** (Boisjoly's ability to influence the management was poor)
- NASA engineers did not know that the final **Morton Thiokol** "Launch" decision was not unanimous. (Communication issue)

Socratic Method: these issues are of concern! One should make decision on these issues with respect to safety, health and welfare.

Case B: The Challenger Disaster

The Launch:

- Contrary to weather prediction the overnight temperature was 28^{o}F. **Due to the extremely low temperature the O-ring didn't seat properly.**

- The shuttle exploded soon (73 sec.) after lift off on 28 Jan. 1986.

Case B: The Challenger Disaster

The Aftermath:

- After President Ronald Reagan ordered a presidential commission to review the disaster, Boisjoly was one of the witnesses called. He gave accounts of how and why he felt the O-rings had failed. After the commission gave its findings, Boisjoly found himself shunned by colleagues and managers.
- The investigation also revealed that, long before the disaster, **Boisjoly sent a memo describing the O-ring problem to his managers, but was apparently ignored.** Following several further memos, a task force was set up—including Boisjoly—to investigate the matter, but after a month Boisjoly realized that the task force had **no power, no resources and no management support**. In late 1985 Boisjoly advised his managers that if the problem was not fixed, there was a distinct chance that a shuttle mission would end in disaster. No action was taken.
- His actions hurt the efforts of Thiokol. He was isolated in the company. Eventually, he took a medical retirement after the accident.

What else could Roger Boisjoly have done?

External Whistle Blowing?

Case B: The Challenger Disaster Epilogue

- **Several families sued NASA management**
  - between $2 and 3.5 million per family.
  - Morton Thiokol paying 60 percent
- **Roger Boisjoly, Thiokol engineer**
  - testified before Congress
  - left the company
  - underwent therapy for post-traumatic stress disorder
  - awarded the Prize for Scientific Freedom from the AAAS,
  - Boisjoly became a speaker on workplace ethics (in Australia)
  - Boisjoly died on January 6, 2012, of cancer of the colon, kidneys, and liver.

Case B: The Challenger Disaster

Question: What were the ethical obligations for the engineers?

Did **Morton Thiokol** engineers violate their duty to put public safety first?

- The point here is due to the position of Boisjoly, **his ability to influence the management was poor.** Poor decision making based on "group think".

External Whistle Blowing?

- **This example demonstrates how courage, honesty, and concern for safety is important in engineering practice.**

Case B: The Challenger Disaster
A final Question

- Can you suggest ***a creative middle way solution*** between the disastrous decision to launch the Challenger on January 28, 1986 and to postpone it?
- The creative middle way solution should address both the goal of eliminating the risk of the malfunctioning **O-rings** and at the same time allow NASA to keep its commitments for **on-schedule launches**.

Balance his duty to the public (safety) and to his company

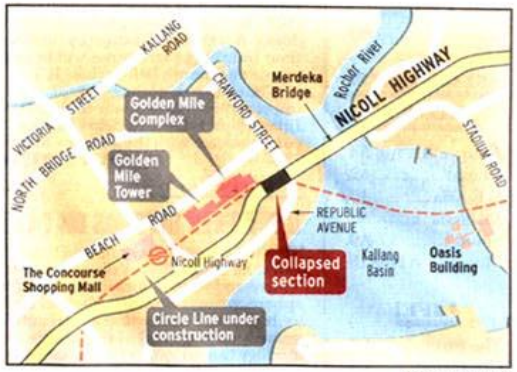
Case C: Nicoll Highway Collapse (Singapore)
20 April 2004, 3:30pm

Nicoll Highway Collapse (20th April 2004)

Four Died: crane operator, construction worker, inspector of works and construction supervisor

MRT worksite collapse wrecks Nicoll Highway

- One dead, three hurt, three missing
- Thousands of commuters hit
- Highway will stay closed for months



ST GRAPHICS

By SHARON LOH

A MASSIVE collapse of a Mass Rapid Transit (MRT) construction site yesterday afternoon wrecked a stretch of Nicoll Highway, which will now be closed for many months.

The mid-afternoon accident near the Merdeka Bridge killed one construction worker and injured three others. Three men were missing and feared dead.

By last night it appeared that the accident occurred after a temporary supporting wall for a tunnel of the MRT's Circle Line collapsed.

There might have been more casualties, except that most of the site workers were having their tea break when the tragedy happened.

While completion of the Circle Line now looks likely to be delayed, thousands of commuters must now use alternative routes into and out of the city, and put up with congestion for several months while the highway is repaired.

The volume of traffic disrupted is unprecedented, the Land Transport Authority (LTA) said.

Everything happened very quickly yesterday afternoon.

Thai construction worker Vehakul Somchia, 28, was bringing tools down to the site at about 3.30pm when he saw a crane and wall collapse.

He dumped his tools and ran.

"I just knew that I must get off this bridge or I would fall in and die," he said. "When the crane sank into the ground there was a man inside."

Within minutes, the surrounding area caved in, leaving a gaping ravine 30m deep strewn with twisted steel beams, rubble, cranes and excavators.

Motorists ground to a halt in time, as a 100m stretch of the highway collapsed.

Home Affairs Minister Wong Kan Seng arrived at the scene and assured the public: "There is no indication that this is foul play."

Transport Minister Yeo Cheow Tong, who came in the late afternoon, said the surrounding buildings were safe, and the top priority now was the search and rescue operations, involving some 75 firefighters and rescue dogs.

'THERE IS NO INDICATION THAT THIS IS FOUL PLAY.'

— Home Affairs Minister Wong Kan Seng

'JUDGING FROM THE SCALE OF THE IMPACT, IT WILL BE MANY MONTHS BEFORE WE CAN OPEN THE HIGHWAY.'

— Transport Minister Yeo Cheow Tong

The body of a Malaysian crane operator in his 40s, Mr Vadivil Nadason, was brought out at 6.15pm, while search teams worked on to find three others believed to have been driving machinery at the bottom of the site when the wall came down.

Three others were injured and taken to hospital. Two were later discharged from Tan Tock Seng Hospital — an Indian national, 25, and a Singaporean, 47, both with leg injuries.

A Thai worker, 21, with head injuries is still at the Singapore General Hospital.

Even as curious onlookers crowded the area, police cordoned off Merdeka Bridge and sealed all roads leading to Nicoll Highway.

The impact of the accident was felt far and wide.

As Nicoll Highway sank, gas, water and electricity cables snapped, causing power to go out for about 15,000 people and 700 businesses in the Marina and Suntec area.

Tenants and residents in the Golden Mile Complex, near the collapsed stretch, were also evacuated.

Several callers to The Straits Times said they heard an explosion, while others reported blackouts.

Though some eyewitnesses said they saw flames flash across Nicoll Highway, the LTA said it had no evidence of an explosion.

When leaking gas was detected, Power Gas shut off the supply to the severed pipe, said Mr Rajan Krishnan, LTA's director of projects, at a news conference last night.

The loud sound of the collapsing wall "might have sounded like an explosion", he said.

Electricity was restored at 3.50pm.

The huge boom which sounded at 3.30pm sent many office workers scurrying to their windows, to be stunned by what they saw.

From his 18th-floor office at Golden Mile Tower, Mr Vincent Chan, 28, said he heard a loud sound "like a huge aircraft approaching the building".

Rushing to the window, he saw a ball of fire on the far side of Nicoll Highway.

"Then the steel reinforcements lying horizontally across the road started to fall into the hole one by one, like dominoes," he said.

Others ran out of their buildings for safety.

Ms Sirirat, 48, a permanent resident from Thailand, was sewing in her shop on the first floor of the Golden Mile Complex when she heard a loud bang.

"I saw many women running out of their shops," she said. "They said: 'Gas explosion! Run for your life'. So I followed them. I thought it was a bomb."

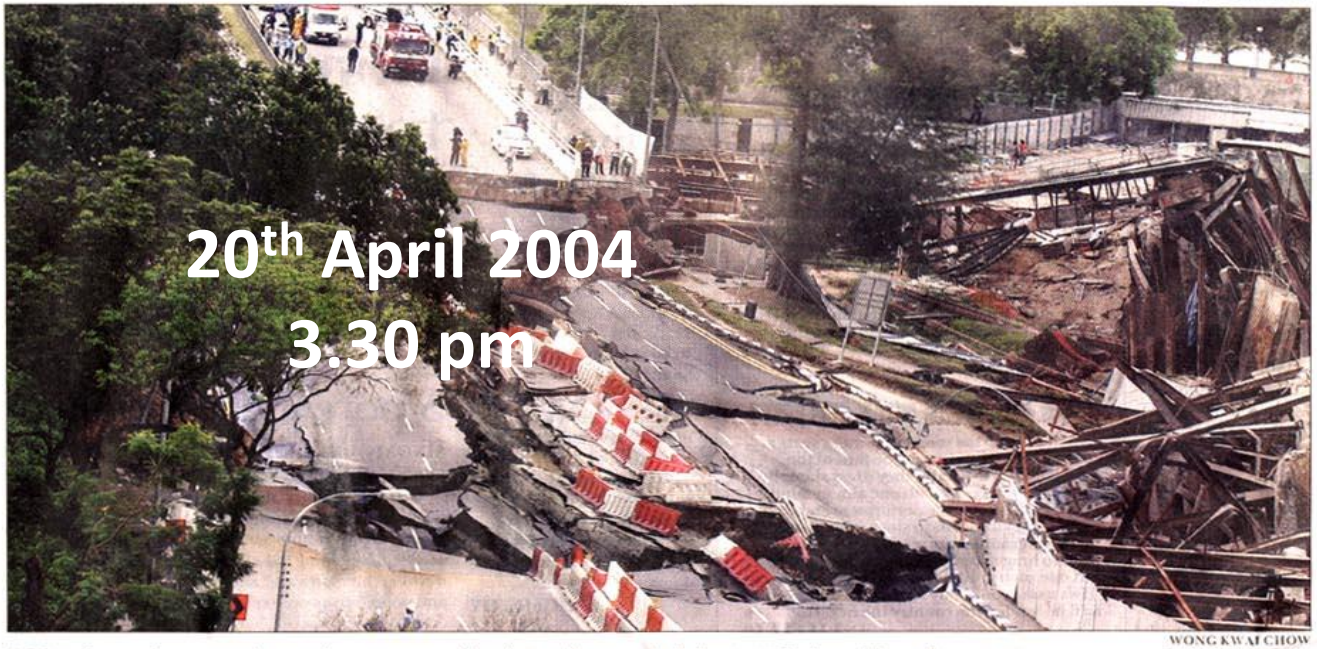
Speaking to reporters yesterday, the Transport Minister said the LTA would now stabilise the ground and ensure the buildings in the area remained secure.

"Tunnelling has been going on for many years but this has never happened before," he said.

"LTA will do its utmost to repair the damage and the rest of the Circle Line project will continue."

The LTA said it could be six to nine months before Nicoll Highway might be opened again.

[More reports and pictures, HOME: H1-H3]



WONG KWAI CHOW

A 30m-deep ravine opened up within minutes of the first collapse, which has initially been blamed on a temporary supporting wall.

What Happened

- The disaster struck on Tuesday 20 April 2004 at about 3:30 pm
- **Occurred after a temporary retaining wall of the tunnel at the Mass Rapid Transit (MRT) Circle Line construction collapsed**.
- Caused a cave-in and brought the surrounding area and the highway down into it, forming 30m deep ravine.

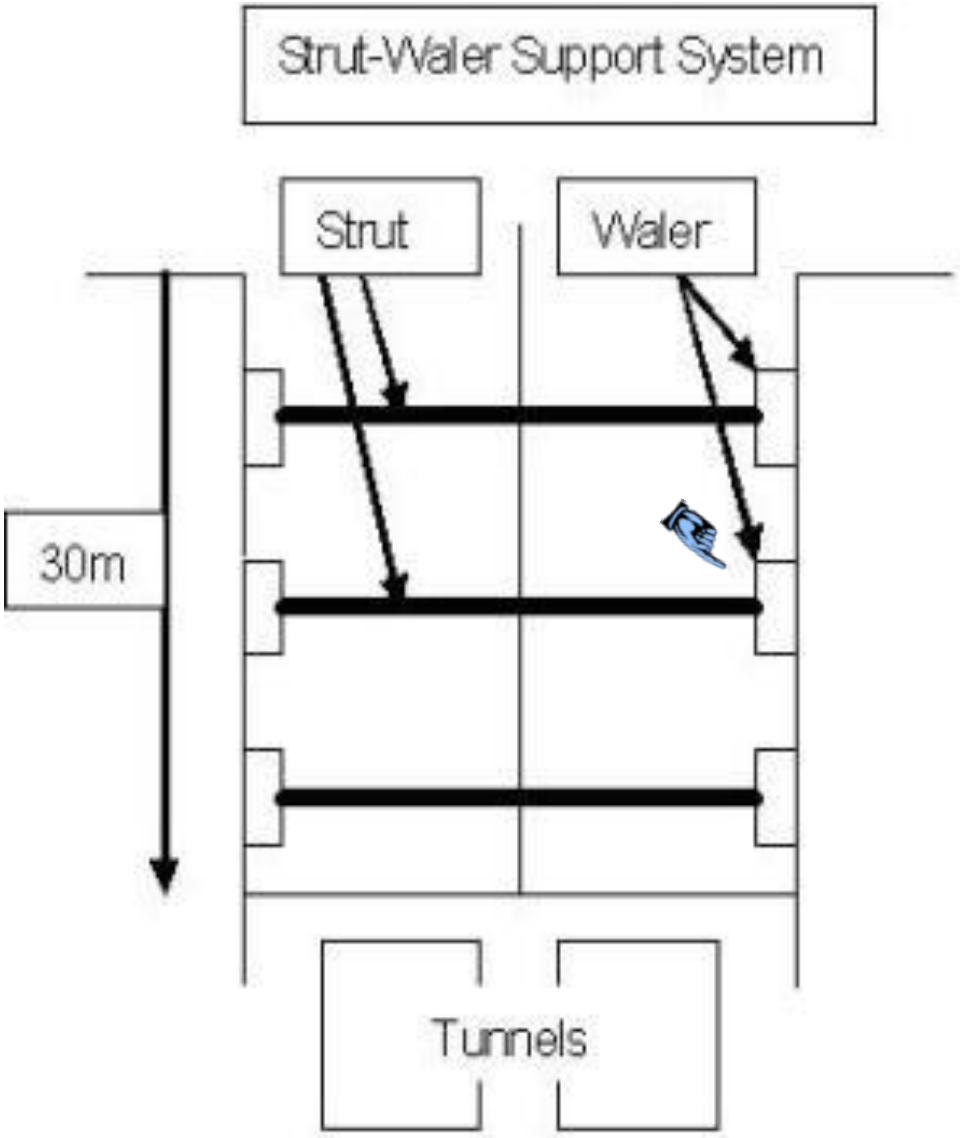
Impacts

- Gas, water and electricity cables snapped, causing power to go out for about 15,000 people and 700 businesses in the Marina and Suntec City area.
- Police had to cordoned off the adjoining Merdeka Bridge and seal all roads leading to Nicoll Highway, affecting thousands of commuters.
- Excavation works at all MRT Circle Line sites under the charge of the main contractor were temporarily suspended.
- The cost of damages arising from the disaster was estimated to run into millions and it was about eight months before the Nicoll Highway is opened again.

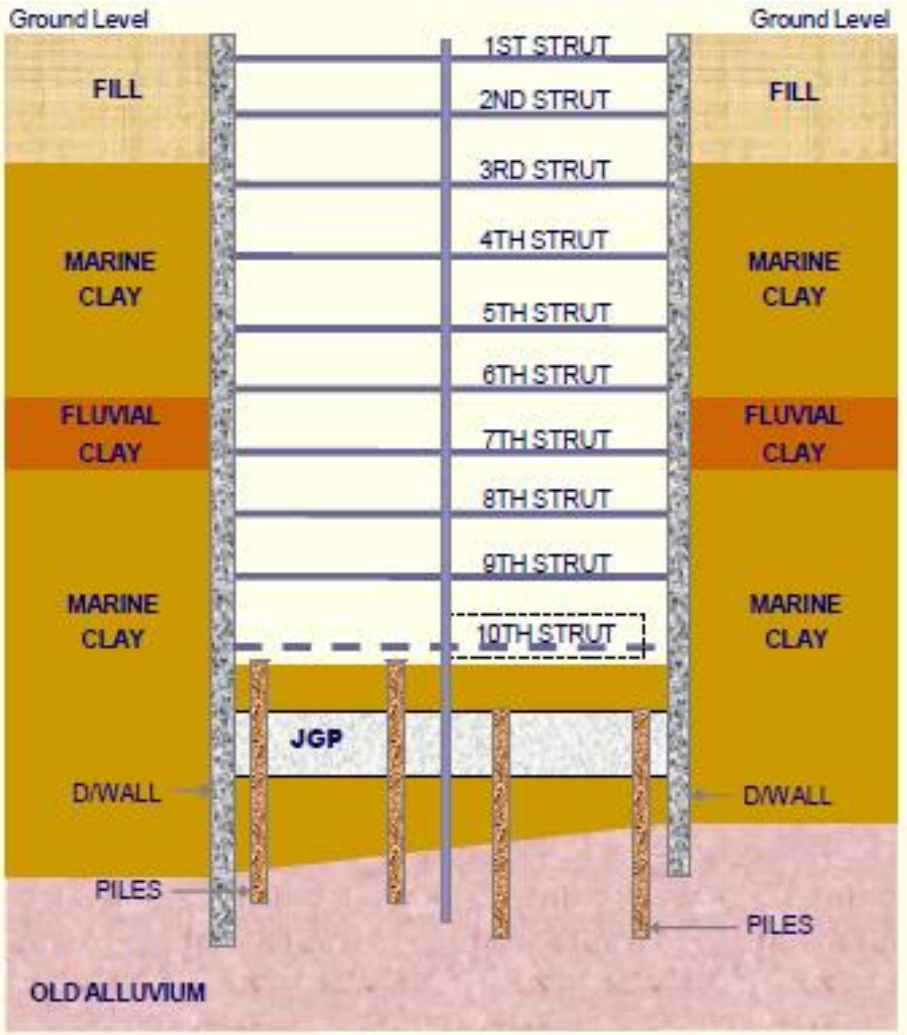
Cut and Cover Method

- The "**cut and cover**" method to construct the **underground tunnels between the Nicoll Highway and Boulevard stations**.
- A large cavity, with retaining concrete walls, is progressively excavated from ground level to tunnel depth, which in this case was 33 metres.
- As the cavity gets deeper, the retaining walls are braced with a **strut-waler support system**.
- This system comprises **steel bars (struts)** which are connected to bars running parallel to the walls (**walers**). The purpose of the walers is to distribute the forces exerted by the struts along a larger surface area of wall. When work is completed within the cavity, it is filled back with soil.

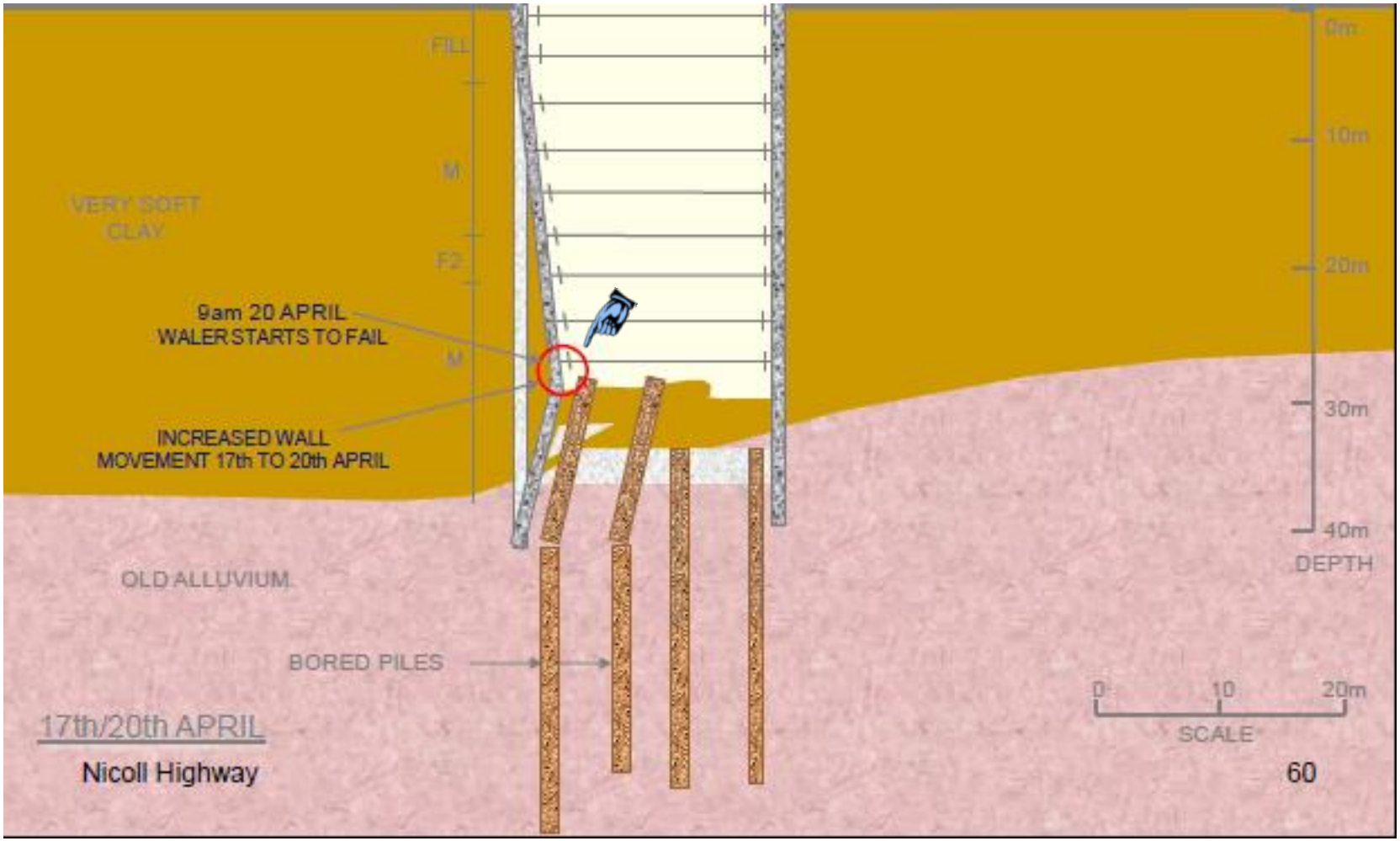
Strut-Waler Support System



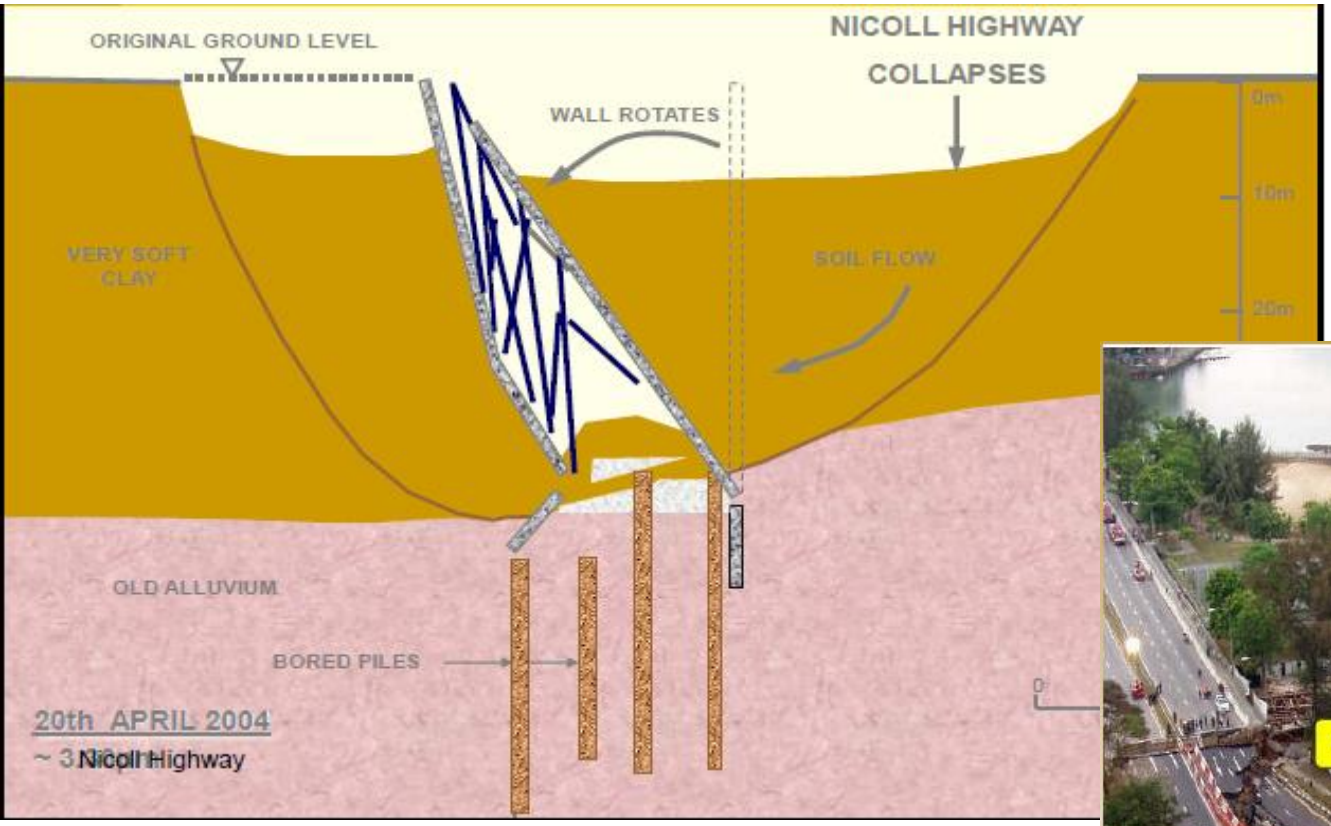
How Did It Happen?

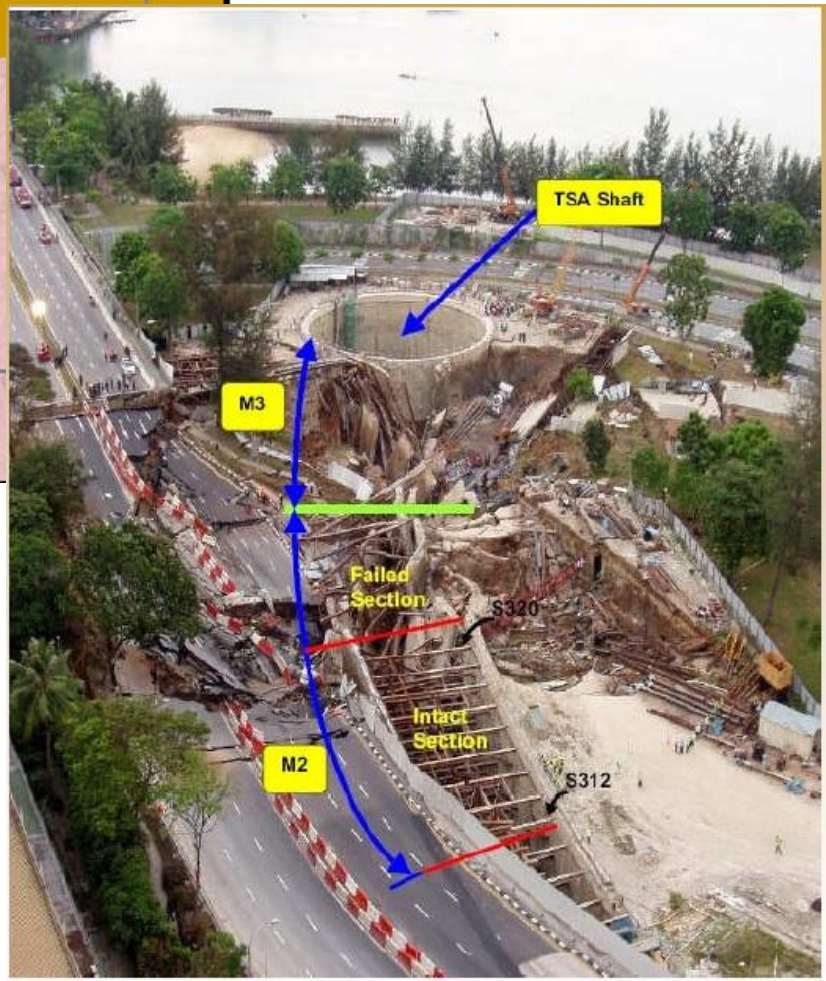


Pre-Collapse



Post-collapse





At about 3.30pm on 20 April 2004, a collapse occurred at part of the excavation site known as "Type M3", which was directly adjacent to the Nicoll Highway.

At the time of collapse the cavity had reached about 30 m in depth.

Cause of the Collapse

It began with two critical design errors:

1. **Under-design of the diaphragm wall using Method A:**
   - Finite element analysis of ground conditions used the mechanical properties of drained soil - known as Method A when the data for undrained soils should be used)
2. **Under-design of the waler connection in the strutting system:**
   - About 10% underestimation of strut loads at level 9
   - 50% underestimate of wall bending moments
   - 50% underestimate of wall deflections

3. **These design errors resulted in the eventual failure of the 9th level strut-waler connections together with the inability of the overall temporary retaining wall system to resist the redistributed loads as the 9th level strutting failed. The catastrophic collapse then ensued.**

Area of Competence

- An engineer should offer services, advice or undertake professional assignments **only in their areas of competence (NSPE Code of Ethics)**.

- This includes exercising care and communicating clearly when accepting or interpreting assignments and when setting expected outcomes.

- It also **includes the responsibility to call for and to obtain the services of a specialist or an expert if required**. If a certain technique, tool or software to be used is questionable, the experimental nature of the activity should be disclosed fully to all parties concerned.

- This requirement is not just about maintaining a proper standard of care, it actually involves **honesty with one's client or employer and oneself.**

Nishimatsu Construction Company Limited

Cost to Company

1. Maximum fine of $200,000

   (new law increases the maximum fine to $500,000)

2. Spent additional $11.7 millions on rescue operations, reconstruction, checks on nearby buildings

3. Barred from further contracts for 5 years.

4. Damage to reputation

Ng Seng Yoong of LTA - Charges

MORE than two months before the Nicoll Highway collapse, the regulator of building works had expressed concern about the MRT Circle Line worksite. The Building Control Unit (BCU) had written to then Land Transport Authority (LTA) **project director** Ng Seng Yoong, saying it had not received 26 reports of instrument readings that should have been submitted over the past six months.

The latest readings also showed the alert levels being breached at many points. There were more than 2,000 instruments on site that served as red flags for safety breaches.

Ng was told to investigate and inform the BCU about the assessment. But his reply failed to satisfy the BCU, which wrote again to raise more concerns.

By submitting an assessment endorsed by the professional engineer for temporary works, Paul Broome, and not by himself, Ng had not complied with his duties as a **Qualified Person**.

Ng Seng Yoong of LTA

An offence under section 19(1) of the **Building Control Act** for breaching condition 8 of the **statutory duties** in the Conditions of Permit, issued pursuant to section 7(2) of the same and imposed on him as the Qualified Person of Project C824.

Liable on conviction to a fine not exceeding $10,000 or to imprisonment for a term not exceeding 6 months.

***Verdict* - Guilty. Fined $8000**
Ng also face disciplinary action under the Professional Engineers Act

Lessons Learnt

- Structural safety of temporary works is as important as that of permanent works.
  - Structures should be designed according to established codes (e.g. Construction Safety Handbook) and checked by competent persons.

- **Monitoring and instrumentation during construction must be meticulously undertaken with an eye to safety.** 

Case D: Delay of Chandrayaan-2 Launch

India's first moon lander was postponed at the very last 56 minutes on 15 July 2019 due to a **suspected** "technical snag" that was discovered while filling the rocket with cryogenic fuel even though conditions were pressing to go ahead:

- Top scientists and VIPs were gathered and all systems ready;
- The skies were cleared and "India's Space Dreams" (being the fourth country to land on the moon) were about to happen.

Tough and difficult! A Good Ethical Decision indeed!

How could Socratic Method be employed to make such a decision?

Successfully re-launched on 22 July 2019

Apply Socratic Method to Ethical Issues in Engineering

Situation: An engineer discovered his company is discharging toxic chemicals over and above the legal limits into the river. Have spoken to his immediate boss was told to keep quiet and don't be a busybody

Consequences of <u>not</u> keeping quiet (just listing a few):

- Losing your job (financial loss)
- Reflect badly as well as hostility toward you
  - One should not worry about these public opinions and they should only concern themselves with behaving well.

Consequences of keeping quiet (just listing a few):

- Compromising the welfare, Safety and Health (WSH) of the public
  - Failing to safeguard WSH will cause great harm to the public. As Engineers, we should hold paramount the WSH of the public
- Company may eventually suffer high financial losses and other repercussions

Course of Action: Should try to convince his superior and the company to address the problem before external whistle-blowing

Answers to Ethics Questions?

- Sometimes there are **several right answers** to ethics issues...
- Sometimes there are **no right answers** ...
- But, like engineering design problems, **there is a personal best answer.**