Cover-Shield Failure and Falling Incident

at a Hydroelectric Generating Station

A Case Study on Health and Safety in Engineering

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Preface

Health and safety issues are important in engineering, although these topics are inherently broader in nature, overlapping with management and other fields. Most professional engineering associations indicate that health and safety are issues of utmost importance in the practice of engineering. For example, the Code of Ethics of Professional Engineers Ontario (PEO) [1] implicitly includes this idea in stating "A practitioner shall ... regard the practitioner's duty to public welfare as paramount."

Appropriate training and education in engineering health and safety is needed. This need is recognized in many countries, as almost every engineering program to maintain its accredited status must, in addition to meeting a range of criteria, appropriately address the topics of health and safety. The curriculum-content criteria of the Canadian Engineering Accreditation Board (CEAB) [2], for example, state the following: "Appropriate exposure to ... public and worker safety and health considerations ... must be an integral component of the engineering curriculum."

Case studies present a useful and interesting means of delivering education. Minerva Canada and others have in the past developed several useful business- and management-oriented case studies on health and safety. To teach health and safety to engineering students, engineering-oriented case studies on these topics are desirable.

This document is an engineering-oriented case study on health and safety, which helps convey the importance of these issues. For realism, the case study is based on an actual incident and the subsequent investigation [3]. The case study is not intended to be judgmental, but rather to provide a basis for discussion. The case study is set in an engineering situation so as to render it useful to engineering students, but is structured so as to be usable by students of other disciplines and in other settings:

- other technical programs where safety is important (e.g., applied sciences and technology programs),
- programs that interface with technical disciplines (e.g., management and business), and
- training programs within and outside of companies.

Although the case study is oriented towards engineering, it also incorporates management and business issues, since health and safety are topics that must be dealt with in an integrated and interdisciplinary manner. For example, technical issues must be linked to management so that appropriate decisions can be made, and other constraints and criteria - such as the needs for performance, profitability, etc. - must be considered in concert with health and safety.

The author invites feedback and comments from interested parties and users, so that the case study can be enhanced in the future.

Acknowledgements

The author is grateful to Minerva Canada for its support of the development of this case study.

Particular thanks are due to David Meston, a member of Minerva Canada who greatly assisted in gathering information and data and who provided invaluable advice throughout the development effort.

Finally, the author is grateful to Ontario Power Generation for supporting the development of this educational tool by granting permission for an incident at one of its facilities to be used as the basis of the case study. The realism brought to the case study by forming it around an actual incident greatly enhances it.

Synopsis of Incident Considered in Case Study

In 1999, a coupling cover that protects the drive mechanism for the erection bay door at a hydroelectric generating station fell approximately 70 feet to the erection bay floor while the door was being operated. The coupling covers are made up of two sections, each weighing approximately 5.5 pounds. The two mating surfaces of the coupling cover sections are joined by two machine screws on which there are no locking devices. At least two maintenance workers were working in the vicinity. After the incident, the erection bay door was taken out of service and the remaining coupling covers were checked to ensure the machine screws were secure. The relevant plant manager rated the incident as serious and an investigation was conducted.

Introduction

Hydroelectric power presently accounts for about one quarter of Ontario Power Generation's electricity production. Ontario Power Generation operates and maintains 69 hydroelectric generation stations in Ontario. The largest hydroelectric station has a generating capacity of more than 1300 MW (megawatts), and the total installed hydroelectric capacity is more than 7300 MW. The R.H. Saunders hydroelectric generating station is located on the St. Lawrence River near Ottawa and has a capacity of approximately 740 MW [4]. Further details can be found on Ontario Power Generation's web site about electrictity generation [5] and hydroelectric generation [6] (including a description of how a hydroelectric station works).

The R.H. Saunders station contains typical hydroelectric equipment. In one part of the facility is an erection bay where a 300-ton gantry crane operates. This overhead structure consists of a platform, which supports a travelling crane. The west erection bay door (door number 130) provides access to the erection bay for the gantry crane.

The door opening measures 58 feet by 60.5 feet. The door is a five-piece multiplex unit powered by a 550 V (AC), three-phase motor. Three pushbutton stations can be used to operate the door. One pushbutton station is located outside the door at the south (downstream) side. There are two pushbutton stations inside the erection bay, one located at the south side and another located at the north (upstream) side. Each pushbutton station can initiate a raise or lower operation and stop the door. The pushbutton station at the north side of the door has a button to bypass the switches on the safety bars. These safety bars are located on the bottom of the erection bay door and cause it to stop moving should it come into contact with an object or person.

A drive shaft runs across the top of the door opening at an elevation of approximately 267 feet (see Photo 3). The drive shaft has sections joined by three chain-type couplings (see Photo 5). The cast aluminum covers that are mounted over the couplings (see Photo 4) rotate with the couplings as the drive shaft turns to operate the door.

The coupling covers are made up of two sections. Each section weighs approximately 5.5 pounds. The two mating surfaces of the coupling cover sections are joined by two machine screws (of thread length 1 inch, diameter 5/16 inches, and pitch 18 threads per inch) (see Photos 1 and 2). There are no locking devices on the machine screws.

Incident Events

At approximately 11:00 am on Saturday, October 30, 1999, a Regional Maintainer 1 - Mechanical (RM1-M) started to open the west erection bay door from the inside pushbutton station on the south side of the door. The door had raised approximately 6 feet when RM1-M heard a noise at the north side of the door and saw something fall to the erection bay floor (elevation 195.5 feet). RM1-M stopped the door and went to investigate. RM1-M found two halves of a drive-shaft coupling cover and two machine screws for securing the coupling cover, on the floor (see Photos 1 and 2). The coupling cover was from the north drive shaft coupling at a level of 267 feet.

One coupling half fell 71.5 feet, from a level of 267 feet to 195.5 feet, landing inside the erection bay. The other coupling half fell approximately 54 feet, from an elevation of 267 feet to the top of the bottom section of the raising door, at approximately 213 feet. It then landed inside the erection bay at the 195.5-foot level, 11 feet out from the doorway. A second employee had been working in this area previously.

After the incident, the door was isolated using a "work protection" procedure (also referred to as a "lock out" procedure or a "work permit" system). Work protection at Ontario Power Generation is a sophisticated procedure for the isolation and de-energization of plant equipment, sub-stations or power lines from all dynamic or stored sources of energy so it is safe to do maintenance or other work. Since most major systems/equipment are interlocked at Ontario Power Generation and operated remotely from a control room, maintenance work must be pre-approved by control room operators. They review production needs, safety, etc. and then isolate and de-energize the necessary equipment, before issuing the appropriate maintenance work permit.

The covers on the two other drive shaft couplings were then inspected. Two machine screws on the south coupling cover were tightened 1/8 turn each. One machine screw on the centre coupling cover was tight and the other machine screw was tightened 1/8 turn. The door was returned to service. An incident report was completed the next regular work day, November 1, 1999.

The Ottawa St. Lawrence Plant Manager rated the incident as a High MRPH (maximum reasonable potential for harm) incident, and requested a System Safety Incident Investigation be conducted. Note that MRPH is a generic risk analysis concept in which the potential consequences of an incident are ranked as high, medium or low. At Ontario Power Generation, the level of investigation is more detailed for the higher risk incidents.

INVESTIGATION TERMS OF REFERENCE

On November 3, 1999, a full investigation was initiated with the following terms of reference:

Client (person for whom the report is prepared)

Vice President, Hydroelectric, Electricity Production, Ontario Power Generation

Investigation Team

Leader: Senior Safety Consultant, Human Resources, Electricity Production, Ontario Power Generation

Member: Regional Maintainer - Electrical, Stewartville G.S., Ottawa St. Lawrence Plant Group, Electricity Production-Hydroelectric, Ontario Power Generation

Member:TMS (Trades Management Supervisor) - Mechanical, Chenaux G.S., Ottawa St. Lawrence Plant Group, Electricity Production-Hydroelectric, Ontario Power Generation

Objective

To describe what happened, identify root causes and recommend corrective actions to prevent a recurrence.

Scope

The Investigation Team was requested to summarize the sequence of events leading up to the incident, the incident itself, and the actions taken immediately following the incident. The investigation included, but was not limited to:

- inspection and maintenance (e.g., its existence and adequacy), and
- the attachment design to keep the cover shield in place/secured (e.g., its type and adequacy, the impact of removal and re-use, the effect of vibration).

Deliverables

The Investigation Team was to:

- present a concise report to the Client that includes the following:
    - incident description and findings
    - root causes
    - recommendations based on root causes
- summarize its work at a VP review

Schedule

Start Date: November 4, 1999

Draft Report to Client: November 22, 1999

Client's Review: To be determined, but before December 4, 1999

Final Report to Client: One week after Client review

Analysis used in the Investigation

The incident was analysed to develop a clear understanding of how it occurred and to derive findings and their significance, conclusions and recommendations.

The analytical techniques used were as follows:

- **Root Cause Analysis**. A root cause analysis tool was used by the Investigation Team to identify the root cause of the incident. Root cause analysis helps investigators identify the causes of equipment problems and human performance problem areas (e.g., procedures, training, etc.). Events and causal factors charts are used throughout an analysis. Once the root cause was identified, the Team was able to recommend to management the most reasonable fix(es) to implement to prevent a recurrence. Here, the Investigation Team used the TapRooT® root-cause tool, which is a proprietary system to guide experienced & novice investigators to root causes [7].
- **Documentation Review**. A review of a number of acts, regulations, codes, work procedures, safety rules, etc. was under taken during the course of the incident investigation.

The documents reviewed during the Saunders Erection Bay Door Investigation included the following:

1. B. M. Basaraba, *IPT's Industrial Trades Handbook: Power Transmission Systems*, 1999 (see http://www.iptbooks.com/handbook_05.htm for more details).
2. "Mechanical Maintenance Procedures Manual," section on "Doors - Power Operated," Ontario Hydro.
3. All relevant EWMS (Electronic Work Management System) Orders. (The EWMS is used to plan and schedule work, assign resources, coordinate outages, track inventory, etc.)
4. "1997 Hydroelectric Programs Definitions," Appendix A: Typical Equipment Mapped to HBU (Hydraulic Business Unit) Program, Ontario Hydro.
5. Relevant past correspondences.
6. Corporate Report of Incident/Injury dated November 2, 1999.
7. Notes of conversations and discussions that occurred subsequent to the incident.
8. Corporate Safety Rule Book, Ontario Hydro.
9. Ontario Hydro's "Guidelines for Selecting Maintenance Strategy Categories" [8].
10. R.H. Saunders, Richard Wilcox Doors Maintenance Schedule, Ontario Hydro.

Relevant Historical Information NOTED DURING INVESTIGATION

The west erection bay door (door number 130) is original to the plant and maintenance responsibilities were turned over to the plant in January 1960.

The 1960 document transferring maintenance responsibilities for the west erection bay door includes servicing instructions. These servicing instructions have been put into a check-sheet format to facilitate routine inspections. Inspections of door components are scheduled on a monthly to 6-month basis. The inspections include checks of oil levels, chains, brakes, cables and gearcases. There was no record of these checks having been performed in the maintenance file reviewed by the Investigation Team.

The maintenance file reviewed by the Investigation Team had documented evidence that mechanical maintenance was done on the door in October 1983, July 1984, October 1989 and February 1996. The work in 1989 was described as "...emergency inspection and repair..." and was performed by an external service provider. The work in 1996 was conducted with technical assistance from an external service provider.

A maintenance plan for this door was created in EWMS in December 1996 and had not been used to the time of the incident.

This door is categorized as non-production equipment. This categorization is significant since, according to Ontario Power Generation [8 (p. 3)]:

"These are the lowest priority systems and work on these systems often gets deferred, however maintenance on these structures/systems cannot be forgotten as eventually this will lead to failures which will have an overall impact on the facility."

The investigation report noted an additional relevant point. There is a history of problems with the switches on the safety bars mounted on the bottom of the door. Typical failures stop the door from being lowered after it has been raised. Electrical maintenance installed a bypass switch in conjunction with the north pushbutton station in order to lower the door to repair the switches when they fail. The bypass button must be held down manually in order to lower the door. However, the safety bar switches continue to fail and the bypass switch is being used for the normal operation of the door rather than as a maintenance-assist device. The safety bar was defective on the day of an examination by the Investigation Team and the door was being lowered using the bypass switch.

Findings, Conclusions and Recommendations of the investigation

The root cause of the incident was determined by the investigators to be "equipment design" as related to the design of the cover plate. In addition, two other factors that contributed or were related to the incident were identified: insufficient maintenance, and problems with the safety bar on the erection bay door.

Consequently, three issues were identified as leading to recommendations. Each of these issues is discussed below, in terms of the findings and their significance and the subsequent recommendations made.

Issue 1: Design of Cover Plate

Findings and their significance

The following points related to the design of the cover plate were identified:

- The design of the coupling cover did not prevent the coupling machine screws from backing out to the point where the coupling came off and fell to the erection bay floor.
- The coupling cover was designed to prevent dust and dirt from getting in the lubrication and to prevent excessive lubrication from being thrown from the coupling.

The significance of these findings is that if the design of the coupling cover had a locking mechanism to prevent the 1-inch long machine screws from vibrating loose, this incident would have been prevented.

Recommendation

There is a need for the Ottawa St. Lawrence Plant Manager to ensure the remaining coupling machine screws are replaced with machine screws with nylon locking inserts or an equivalent locking mechanism.

Issue 2: Maintenance Needs Improvement

Findings and their significance

The following findings were drawn regarding the maintenance of the equipment involved in the incident:

- The erection bay door at Saunders hydroelectric generating station is a Richard Wilcox door and was part of the plant's annual maintenance schedule up until 10 to 12 years ago.
- The Richard Wilcox erection bay door and gates maintenance recommendation covers off a number of items to be checked on a quarterly to semiannual basis.
- The Saunders erection bay door has been overhauled a number of times in the past few years (October 1983, July 1984, October 1989 and February 1996).
- The erection bay door has been part of the EWMS inventory since December 1996. However, the erection bay door falls within the fourth maintenance strategy category (that for non-production equipment) [8]. Therefore, maintenance has not been scheduled for the erection bay door unless it is an emergency.
- The erection bay door is categorized as non-production equipment. As pointed out earlier, such equipment and systems often receive the lowest priority and work on them often gets deferred, even though their maintenance can not be forgotten as eventually this will lead to failures [8].

The significance of these findings is that if the Mechanical Maintenance Department had scheduled the erection bay door for annual maintenance this incident may have been prevented.

Recommendation

There is a need for the Vice President, Hydroelectric to ensure that a risk assessment is conducted on all non-production category equipment. This assessment is needed to identify the risk to staff and other equipment if a piece of non-production equipment catastrophically fails due to the low maintenance priority placed on non-production equipment.

Issue 3: Safety Bar on Erection Bay Door

Findings and their significance

The following are the findings related to the safety bar on the erection bay door and the associated equipment:

- There is a history of malfunctioning problems with the safety pressure switches that are a component of the safety bar that is attached to the bottom of the erection bay door.
- The push button station-lowering button cannot lower the erection bay door when the safety bar malfunctions.
- The Electrical Maintenance Department installed a bypass switch on the north push button station in order to lower the door and repair the safety bar switches when they malfunction. This action is in contradiction of Corporate Safety Rule #110, item #2.
- Corporate Safety Rule #110, item #2 states that safety interlocks must not be bypassed by the use of devices such as jumpers or spare keys, unless written authorization is obtained from a department manager and the appropriate employee representative (i.e., Chief Steward or delegate for the employee's union and/or society delegate, and local Joint Health and Safety Committee (JHSC)). This action was not done prior to the installation of the bypass switch.
- The safety bar switches continue to malfunction and the bypass switch is being used for the normal operation of the erection bay door, instead of as a maintenance-assist device.
- The safety bar was malfunctioning on the day the Investigation Team was conducting the investigation and the bypass switch was being used to lower the door.

The significance of these findings is indirect. The Investigation Team does not feel this issue had any bearing on the outcome of this incident. However, the safety bar is a safety mechanism that should be operating properly and, therefore, it should be properly maintained and in good working order.

Recommendations

Two recommendations were drawn from these findings:

- There is a need for the Ottawa St. Lawrence Plant Manager to have the push button bypass switch replaced with a key operated switch to ensure the bypass switch is used only as a maintenance assist device to lower the erection bay door when it malfunctions.
- There is a need for the Ottawa St. Lawrence Plant Manager to ensure the safety bar on the erection bay door is repaired and placed on a regular maintenance schedule.

FATE of the investigation REPORT

The incident investigation report described herein was delivered to the Vice President, Hydroelectric, who has a responsibility both to review it and to take any necessary actions (or seek approval to do so).

CLOSING REMARKS FOR THE CASE STUDY

This case study describes an actual safety incident that occurred in an engineering facility and the investigation that followed, including the recommendations made. Although there were fortunately no injuries, the incident was nevertheless very significant as the potential for serious injury existed.

A reader may question the significance of this case study at this point, given that there was no loss or injury. However, the selection of such an incident was intentional. It was the authors desire not to present a case based on a disaster (as is commonly done with case studies), but rather to present a case which is based on the much more common situations faced routinely by industry. Even though no loss or injury occurred in the present case, the incident described was serious because the potential for injury or loss of life was great.

The case study raises several very interesting points related to the principles of both engineering safety and the emerging discipline of Safety by Design [9,10]. Some notable points raised:

- The causes of safety incidents in engineering situations often involve technical as well as non-technical factors such as issues involving people and management.
- The differences in the ways production and non-production equipment are treated can have a significant effect on safety.
- Safety risks are often introduced when means are set up to bypass safety systems, especially when they become routinely used.

In addition, it is pointed out that this case study should cause readers to think about the ways in which companies address safety-related incidents. Only sophisticated companies investigate "near misses" to the great extent described here, and treat them as opportunities to learn. Most companies would probably investigate this incident only in a minor way, if at all, and then move on. The level of investigation would only have been scaled up for most companies if someone had been seriously injured, especially if regulatory authorities became involved.

Finally, it is noted that the development of this case study helps fulfill one of the needs identified in a recent engineering workshop on safety by design [18]. One of the conclusions reached was that "Engineering faculty need a pool of good health and safety resources to draw upon · Resources should include · case studies, success stories and examples of disasters."

The questions presented below are intended to promote thought and discussion of these and other topics related to the case study.

Questions for Consideration and Discussion

1. Which recommendations do you feel should be implemented, and why? For those recommendations you feel should not be implemented, explain your reasons.
2. Do you feel any other recommendations should be made? If so, describe them.
3. Do you agree with the finding of the Investigation Team that the root cause of the incident was a safety design problem with the cover plate? Some engineers who have reviewed this case have suggested that the root cause was not design, but inadequate maintenance. Comment on this view.
4. Do you feel that the main factors contributing to the incident were technical (e.g., equipment design specifications) or non-technical (e.g., related to management, human factors, communications, etc.).
5. The concept of non-production equipment having a lower priority for maintenance than production equipment is raised in this case study. Comment on this concept in terms of its impact on (a) company productivity and (b) safety. Also, discuss how you would deal with these different equipment categories in terms of safety.
6. It is often stressed that it is best to address health and safety comprehensively in the early stages of an engineering activity, preferably within the design process and not as an afterthought. Do you feel that safety issues were adequately dealt with early on for the equipment involved in the present incident? Justify your answer and suggest relevant improvements.
7. Some findings and recommendations (i.e., those related to issue 3) were not directly related to the incident but were reported nonetheless. Although this material was somewhat outside of the scope of the investigation, especially given its Terms of Reference, do you feel that it was appropriate to include it in the report? Can you infer any general safety principles from this matter (i.e., the discovery of safety concerns that are outside the scope of an investigation)?
8.
9. In general, investments in safety by companies are sometimes sacrificed to try to increase profitability. Do you feel that economic factors could have played a role in this incident?

10. Ontario Power Generation presently has a project to develop a Safety by Design manual [9]. Also, Professional Engineers Ontario has developed a generic guideline aimed at providing professional engineers undertaking a safety review with guidance on the recommended level of diligence, methodology and reporting [11]. What suggestions for material to be included in those guides can be drawn from the present case study? Also, list the ways that you feel Safety by Design principles may have been violated in the present incident.
11. Event-tree and fault-tree analyses are often used by engineers to assess the occurrence probabilities of different types of accidents, and the possible consequences [12-17]. Use these analysis techniques to identify (a) the probability of the type of failure that occurred, (b) the probabilities of a recurrence of the failure if each recommendation is implemented separately and if all the recommendations are implemented simultaneously. Also, determine the maintenance frequency that would be needed to reduce the risk of recurrence to a "reasonable" level, where reference materials should be examined to determine what may be considered reasonable. Further, consider other types of consequences (e.g., human injury or death) and assess the probabilities of them occurring for the scenarios described in (a) and (b), above.
12. Consider the recommendation that the remaining coupling machine screws should be replaced with machine screws with nylon locking inserts or equivalent locking mechanisms. Suggest some equivalent locking mechanisms that may be suitable. Also, try to assess, using engineering techniques, (a) how much tendency exists for the machine screws to loosen, and (b) how much force/torque the locking mechanism will have to provide to stop the screws from loosening in the future.

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LIST OF PHOTOGRAPHS

Photo 3. The erection bay door and drive shaft at the Saunders hydroelectric generating station.

Photo 4. The installed drive-shaft coupling covers on the erection bay door at the Saunders hydroelectric generating station.

Photo 5. The installed drive-shaft coupling, with the coupling covers missing, on the erection bay door at the Saunders hydroelectric generating station.