Journal of Technology (www.jotechno.com)
Volume 29, Special Issue 1, July. 2014, Pages 80-90
ORIGINAL ARTICLE

Engineering Ethics Case Study of Hydroelectric Sayano-Sheshenkaya Accident: Lesson Learned for Malaysian Engineer

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Abstract. Sayano–Shushenskaya hydroelectric power station can be categorized as the biggest hydro power plant in Russia. The power plant full capacity is 6500MW. It is made up of 10 turbines which is each turbine rated power is 650MW. The accident that happened in the power station have been claimed many lives and high cost of damage. All people are keeping asking about the main causes of this tragedy. In order to know the causes of this tragedy, a study case needs to be conducted in order to relate the study with the engineering ethical theory. The goal of this case study is to study about the main causes of the accident that is related with the code of ethics and find the lessons that can be taken from the accident toward Malaysian engineer. This case study shows most of the causes of the accidents are related to the engineering ethical theory. The results of the findings really indicate the important of following the code of ethics in the working environment. The safety of the hydro plant resources is depending on the people who are conducting the plant in a proper manner.

Keywords: Engineering ethics, ethical theory, code of ethics.

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1 INTRODUCTION

Accident at Sayano-Shushenskaya hydroelectric power station can be say as one of the biggest accident occur in Russia that cause 75 people dead, 40 tons of oil transformer traveling down the river which cause the environment impact, power supply failure which resulting blackout to residential area and billions of losses to company that connect to the grid with Sayano hydro plant.

Sayano–Shushenskaya hydroelectric power station is located on the Yenisei River, near Sayanogorsk in Khakassia. Before the accident, it was well known as the largest hydroelectric power station in Russia and the sixth-largest hydroelectric power station in the world, by average power generation. The plant is operated by RusHydro. On 2 July 2009, RusHydro announced the station's all-time highest electricity output per 24 hours [1].

Figure 1. Location of Sayano–Shushenskaya and Bratsk hydroelectric power station.

The Sayano–Shushenskaya plant is operated by RusHydro. It provides more than a quarter of RusHydro's electric generation capacity [2]. It operates by using ten types of hydro turbines series of PO-230/833-0-677 [3] which manufactured by Leningradsky Metallichesky Zavod, each unit with a generation capacity of 640 MW at 194 meters (636 feet) above head [4]. The total capacity of the plant is 6,400 MW and the average annual production is 23.5 TWh, the highest production is in 2006 which producing at 26.8 TWh.

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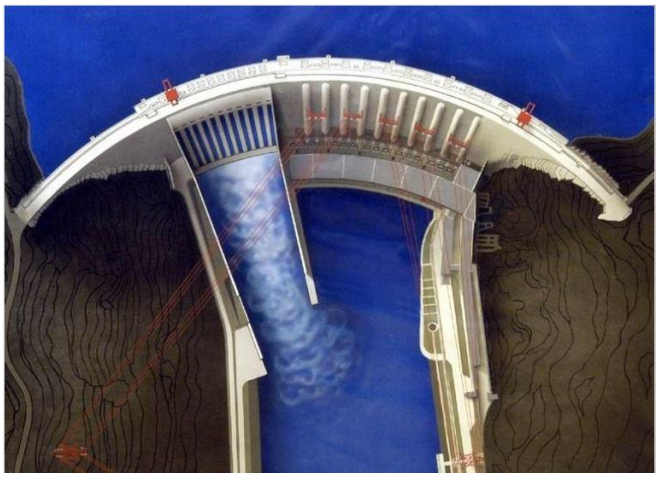
Station construction including dams, building power plants located near the dam, and additional spillway. Arch-gravity dam is 242 meters (794 feet) high. It has a crest length of 1,066 meters (3,497 feet), the peak width of 25 meters (82 feet), width of base 105.7 meters (347 feet) and a maximum head of 220 meters (720 feet). It consists of a solid left-bank dam 246.1 meters (807 feet) long, a power dam 331.8 meters (1,089 ft) long, a spillway dam 189.6 meters (622 feet) long and strong right-bank dam 298, 5 meters (979 feet) long [5].



Fi**gure 2.** Top view of Sayano-Shushenskaya hyproelectric.

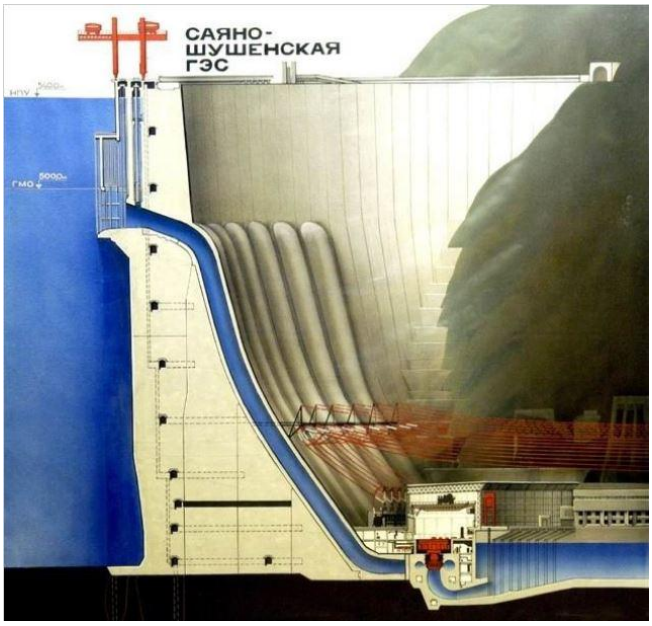


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Figure 3. Slit dams and machine room.

The dam was built to a 'safety' to be able to withstand earthquakes up to 8 on the Richter scale, and was recorded by the Guinness Book of World Records for building the strongest kind. The dam reservoir for Sayano-Shushenskaya support with total capacity of 31.34 km3, 15:34 km3 useful capacity and surface area of 621 km2 (240 sq mi).

The issues start with turbine unit 2 where it has encountered a problem for a long time before the accident in 2009. The problem first appeared after installation in 1979, after that during year 1980 to 1983; there many issue and problems related with seals, vibration of the turbine shaft, and bearings arise. From late March to late November 2000, the complete recovery turbine 2 was performed. Cavities up to 12 millimeters (0.47 in) and cracked up to 130 millimeters (5.10 in) long was found in the turbine wheel and repaired. Many other defects found in the turbine bearings and subsequently repaired. In 2005, repairs were made to the turbine 2. Problems encountered are similar in some aspects to the defects observed during previous repairs. From January to March 2009, turbine unit 2 was undergoing scheduled repairs and modernization. It is the first and only turbine in Sayano–Shushenskaya hydroelectric power station that equipped with electro-hydraulic speed regulator supplied by the Promavtomatika Company. During the repair, turbine blades were welded, because after a long period of operation, cracks and cavities have emerged. Incorrect turbine wheel rebalanced after this repair.

It has now been five year since the catastrophic accident at the huge Sayano Shushenskaya Dam and Hydroelectric Station in southern Siberia which cost the lives of 75 people and nearly destroyed the 6400MW powerhouse.

The objectives of this case study is to find lessons that can be taken from the accident occurred and to find the examples of working environment that do not comply with the code of ethics.

2 PROBLEM STATEMENT

The purpose of this study is to identify the problem that causes this accident to occur and to relate this study with the engineering ethical theory. The study will be starting from gathering all the information related to the accident including the chronology, cause of accident, consequences and unethical act that has been done. Hydropower plants built with ten turbines. Unit 2 turbine started having problems shortly after installation due to defects in seals and vibration of the shaft. Cavities and cracks in the turbine wheel were completely refurbished in 2000. Despite

these efforts, turbine unit 2 continued to have problems, leading to further improvements in 2005 and 2009, in which the turbine blades were repaired. But still experiencing turbine vibration for new cracks and cavities, which does not exceed the threshold. But in July 2009, the vibration exceeds the threshold limit and continues to grow. It is believed that there are several proposals to shut down the turbine and make a replacement to a new one by the engineer, but because of economic pressure, the financial is put ahead of safety.

The life expectancy of the turbine and generation of electricity that push the turbine unit 2 to maximum limit by top management also can be take into consideration that lead to this accident. Other issue associated to this incident is the heavy vibration and poor maintenance associated with studs fail in unit 2 turbine head cover at the factory. This study will be related to ethical awareness. This is done in the interest of implement the import engineering ethics among owners, engineers, managers and operators of hydro plants everywhere in to avoid any biggest accident.

3 ENGINEERING FAILURE CRONOLOGY

The sequence of events leading to the incident began early in 2009. Starting from January to March when three months to repair the turbine unit 2 was completed which included better control of speed regulation. Turbine has synchronized back to the grid on March 16. However, the turbine wheel is not properly balanced again after the repair has been completed. The unit 2 turbine is taken offline (stored in reserves) until August 16, 2009.

3.1 August 16, 2009 at 8:31 p.m

A fire alarm tripped at Hydroelectric Power Station of Bratsk. Siberian Unified Dispatching Control Center (UDCC) was unable to use Bratsk in regulating mode. The UDCC dispatcher ordered Sayano–Shushenskaya Hydroelectric Power Station (SSH) to replace Bratsk in providing load frequency regulation.

3.2 August 16, 2009 at 11:14 p.m.

Dispatchers in Siberia UDCC decided to start Unit 2 (which is kept in reserve) and immediately switches to regulate the mode.

3.3 August 17, 2009

Soon, all the units have been operating in the mode of regulating the exception of unit 6. Unit 6 was undergoing scheduled maintenance and was not in operation.

That day there are more than 100 employees appear to perform repair and maintenances work.

3.4 August 17, 2009 at 8:13 a.m.

The failure start at turbine unit 2 when output power was reduced by the turbine regulator and it entered into the non-recommended powerband zone.

First, the 1,860-ton turbine cover was blown off, leaving the unit 2 turbine in its pit with no turbine mountings. In an instant, the water head pressure from the dam immediately ejected the turbine rotor from the pit. The rotor is continuing to spin as it flew across the turbine gallery, destroyed everything and everyone in its path

As the turbine gallery filled with water, Unit 7 and 9 turbines continued to operate when their safety shutdown systems failed to trip. Eventually, the turbines were submerged, causing extensive damage to equipment and structures.

3.5 August 17, 2009 at 9:30 a.m.

Due power losses the remaining eight units' wicket and head gates could not be closed remotely causing the water continuous to fill the turbine gallery and flash away the entire worker in gallery.

3.6 August 17, 2009 at 11:50 a.m.

The emergency diesel generator was started at 11:32a.m. At 11:50a.m, 11 spillway gates of the dam been opened and 75 people were later found dead.The illustration in Figure 5 shows the turbine gallery before and after the accident.

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Figure 5. The destruction of the turbine, before and after gallery turbine plant.

4 ETHICAL THEORY ANALYSIS

Nowadays, there are many accidents that could be related to the engineering failures. A theory or system dealing with values relating to human conduct, with respect to the rightness and wrongness of certain actions and to the goodness and badness of the motives and ends of such actions [6], [7], [11]. This study need to be concern because to study, defining, analyze and make some recommendation to one of engineering failure accidents that was occurred at Russia Sayano-Shushenkaya Hydroelectric power plan. When said about engineering failures, of course it's pretty much relating with engineering ethics.

After the accident of Sayano-Shushenkaya Hydroelectric was occurred due to the turbine 2 failure, many investigations that have been done to investigate the accident background, to make root cause analysis in order to determined what actually was happen and anything that could be relating with the accident including ethical analysis [8], [9], [10]. In this case study, ethical theory and code of ethical conduct were applied to relate all the problems were happen before the accident.

4.1 Utilitarianism

Utilitarianism is basically seek to produce the most utility, define as a balance between good and bad consequences of an action, taking into account the consequences for every one affected. This theory can be related with this accident

when the decision made by the peoples in Sayano-Shushenkaya Hydroelectric seen to be good and also bad effect.

When Bratsk Power Plant was got problem in producing electrical power, they was forced Sayano-Shushenkaya to operate turbine 2 even at that time turbine 2 was in under preventive maintenance due to the problem with the vibration occurred while it operate. Eventually, turbine 2 was operated to comply with the requirement from the consumers to get enough amount of electricity. At that time, they already knows that what the actual risk going to be happen to that turbine. Therefore in this decision made clearly shows that contain the good and bad consequence.

4.2 Duty Ethics and Right Ethics

Duty ethic contends that there are duties that should be performed regardless of whether this action leads to the most good. For the right ethic, emphasizes that engineer s always have the moral right, and any action that violates these right ethically unacceptable. These ethical theory are very important to be performed in order to avoid any engineering failures because when an engineer always do the right things in his duties, any engineering failures maybe can be avoided.

During the morning of 17 August 2009, 50 people were around turbine 2. As the plant general director, Nikolai Nevolko, was celebrating his 17th anniversary, early in the morning he went to Abakan to greet the arriving guests, and none of the workers present wanted to make or had no authority to make decisions about further actions regarding the turbine [12]. It seems they were used to those high levels of vibration. When relates with ethical theory, the Director doesn't performed his duties and right ethics in his responsibilities. In the right way, he needs to make sure there have any workers at the plant that has the authority to make a decision to stop the turbine during the failure on turbine 2.

4.3 Code of Professional Conduct

By referring the guideline for Code of Professional Conduct that regulated by Board of Engineer Malaysia, registered engineers shall issue public statement only in objective and truthful manner. After investigations have been done by this hydro company, they were release the accident report to the public. This was being a big problem when the other investigation report was not identical with the report issued by that plant management. The top management seem like trying to hidden some real information regarding their own failure to avoid this accident to be happened.

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5 LINE DRAWING PROBLEM SOLVING

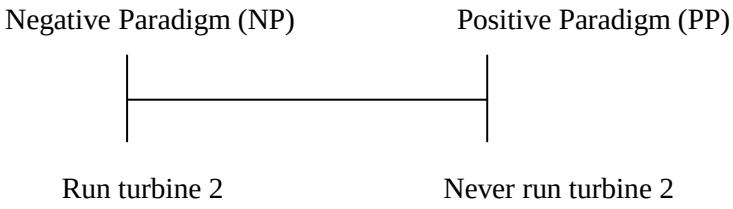

Figure 6. Initial line drawing according to the case study.

Positive paradigm = Never run turbine 2
Negative paradigm = Run turbine 2

Hypothesis:

1. Sayano-Shushenkaya Hydroelectric Power Plant not run turbine 2 and there have consumers with not enough electricity.
2. Director will make sure there one people that have the authority to shut down the turbine.
3. Sayano power plant ask the other hydro power plant to generate more electricity because there have a problem due to vibration occurred at turbine 2.
4. Run turbine 2 to generate more electricity although there have a big risk if run the turbine.
5. Top management asked to replace turbine 2 with new one.
6. RushHydro could not replace the turbine because of economic downturn.

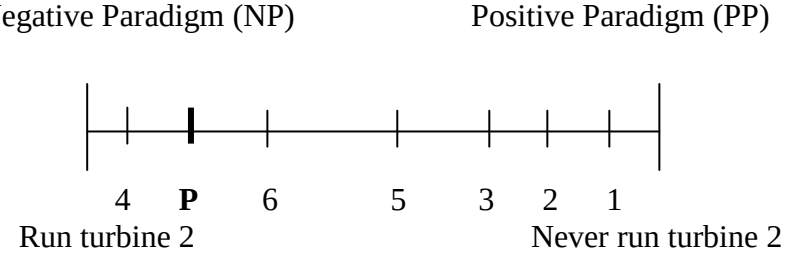

Figure 7. Final line drawing according to the hypothesis of case study.

According to the Figure 7, the approached taken by Sayano-Shushenkaya Hydroelectric Power Plant to run turbine 2 wasn't the best ethical choice.

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6 DISCUSSION AND RECOMMENDATION

The accident was started by the explosion of the turbine 2. The explosion and the destruction of turbine 2, 7 and 9 were probably caused by water column separation in the turbine draft tubes during unit load rejection. Turbine blade had been speeded up to an unsafe level because of the unstable electrical loads that caused the hydraulic transient phenomenon to be happen. Besides, when the turbine blade in this plant want to be adjusted to increase the operating speed above safe levels, it must been done in a good faith. It cannot be done by the operations personnel who were not familiar and do not have any experience in handling the hydraulic transient phenomena.

Next, the plant operators that handling the system were clearly working under the pressure to improve system frequency stability in order to verify the load follow the capability of the plant. The operators of this plant had a strong incentive to speed up the governors, which could have been accomplished easily by replacing orifice plates or adjusting needle valves. On the other hand, the designs of the turbine mechanical should be fulfill the safety requirement and easy for the worker to do an inspections and maintenances. In this case, some of the part of the turbines was not easy to pass through to do an inspections because of the location was not suitable and not particularly visible.

This problem can be considered as the shortfall on the part of the turbine designers. Usually, the plant designers should prepare the Operating and Maintenance Manuals as part of the design documentation. The manual was very useful during undergoing the maintenance and include some limitations and recommendations of using the equipment. Clear warning should be stated in order to avoid an accident to be occurred. In this case, the turbines blade can perform above the limit but it must ensure that the operators caution about the hydraulic transient effects. Lastly, the importance of the hydraulic transient phenomena cannot be taken for granted. Designers must be cautious, and must give that caution to operations people. Hydro plants must be conservatives and have the safe structures. The lack of maintenance and inspections may cause something that unexpected. The continued safety of our hydro resources depends on it.

7 CONCLUSION

The goal of this case study is achieved by applying the problem solving technique of engineering ethics. The results of the findings are hoped to help the engineers in Malaysia to be more ethical in order to handle any critical machine in work place. The code of ethics that has been introduced by the board of engineer need to follow by all the engineers so that the high impact accident can be avoid accordingly.

ACKNOWLEDGE

The authors would like to thank the Universiti Teknikal Malaysia Melaka (UTeM) for all the support given.

REFERENCES

1. RusHydro, "Sayano-Shushenskaya HPP Neporozhny recorded maximum power output", Annual Report, July 2, 2009: 20-70.
2. Ilya Naymushin, "Russian dam disaster kills 10, scores missing". In Reuters, 2009.
3. An Information from www.sshges.rushydro.ru, June 4, 2010.
4. Hydraulic Turbomachines: choice illustrated notable achievements, Polytechnic and university presses romandes, 1995.
5. Tančev, Ljubomir, "Dams appurtenant hydraulic structures", Taylor. pp. 648, 2005.
6. Nael Brakat, Engineering Ethics: A Critical Dimension of The Profession, Internationa Journal of Engineering Pedagogy, 1(2), 2011, 1-7.
7. Brad Stappenbelt, Ethics in Engineering: Student Perception and Their Profeesional Identity Development, Journal of Technology and Science Education, 3(1), 2012, 3-9.
8. Yusuke Kaneko, Engineering Ethics on Fukushima, International Journal of Humanities and Social Science, 3(3), 2013, 253-261.
9. M. F. Sulaima, H. S. Lew, C. Y. Lau, Carolyn K. Y. Lim, A. T. Tazily, A Case Study of Engineering Ethics: Lesson Learned From Building Collapse Disaster Towards Malaysian Engineers, European of International Journal of Science and Technology, 3(2), 2014, 21-30.
10. O. A. A. Ghani, M. Z. Kamruzaman, M. F. Sulaima, M. N. Othman, An Engineering Ethics Case Study Review: Petrobras P-36 Accident, The International Journal of Engineering and Science, 3(6), 2014.
11. J. Fieser, "Moral Issues that Divide Us and Applied Ethics", Book of Ethical Theory, Universiti Teknologi Malaysia, 2008.
12. An Information from www.engineeringfailures.org, "Sayano-Shushenkaya Hydroelectric Power Station Accident", EFO staff, March 2012.