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Juridical Side of ALARP: The Monte Bianco Tunnel

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When the ALARP "as low as reasonably practicable" principle is considered in judgments, this always comprehends a proportionate cost-risk analysis of protection measures: minimum risk has to mean level of safety maximization conditional to a given equitable profit, and maximum profit given a minimum sufficient level of safety. In London Court in 1949, Lord Asquith's definition of "reasonably practicable" in its judgment "Edwards v. National Coal Board", as well as the whole judgment, became the legal basis of a requirement for risk assessments. Since then, ALARP has been officially endorsed and safety measures implemented in governments and enterprises in order to mitigate and manage risks. The study aims to analyse the failures in the Monte Bianco tunnel's accident – which occurred on March 24, 1999 – from a logical perspective in order to develop a higher level of safety based on past experience and that played a central role in generating the current European Directive 2004/54/EC on minimum safety requirements for tunnels. This article reveals the consequences of ignoring the value of ALARP principle. Error analysis in Forensic Engineering are discussed and Gu@larp model contribution is considered.

Keywords: ALARP, Juridical, Forensic Engineering, Fire Investigation, Monte Bianco tunnel.

1. Introduction

The first objective of forensic engineering, in particular of the branch who focuses on post-modern inquiry, is to detect and acknowledge the root at the basis of disasters to further develop the knowledge on the topic. Fires and failures in civil engineering are not uncommon. Thousands of collisions take place around the world each year, and some cause tragic events when they occur induced fire in tunnels. Such events create years of litigation through which involved people aim to receive by courts compensation, health therapy, or in more serious cases, people expect from criminal courts at least the sentencing for manslaughter, vehicular homicide, wrongful driving criminal charges, etc. Moreover, it must be noted the relevance acquired by forensics investigations in providing helpful proofs to judges to determine the verdict in cases and to courthouses. Forensic investigation teams are the spinal column of the accident response system and must have a clearly defined scope of responsibility. The very same teams have a huge liability since every detail collected by them, which for this reason must be as clearly and accurately as possible, will be fundamental to accident reconstruction. Frequent questions that are asked during tunnel investigations concern how the fire started and spread so quickly; how fast the truck was traveling in the tunnel; why it stopped; whether there was a failure in the engine; how the driver behaved immediately before and after the accident (or the user, tunnel operators, firefighters); how the vehicle and tunnel design performed in terms of faults; how the tunnel users died or were injured. In many cases in the UK and Italy, depending on whether the minimum/sufficient level of safety has been achieved, a court will take the case to trial based on an in-depth investigation by forensic engineers to answer all the important questions appointed after an accident. In this study, all the above issues are addressed and the Monte Bianco tunnel accident is used as case study.

2. Legal background of ALARP

The ALARP principle is the outcome of two landmark rulings in the UK, i.e., *Edwards v. National Coal Board* and *Marshall v. Gotham Co LTD*. Both cases involved the lack of safety regulations, especially in the area of risk assessment, in the tunnels of the mines where the victims worked and lost their lives. Today, ALARP, an acronym that stands for "as low as reasonably practicable", is a principle used not only for guaranteeing safety in mines, but also in tunnels, bridges, construction sites, factories and all other workplaces.

In the UK, the aforementioned cases - which highlighted the tragic consequences of the lack of prior risk analysis - led to the creation of the *Health and Safety at Work etc. Act 1974*. Remarkably, the legislation has continued to progress since then, often in response to major accidents. As mentioned earlier, two legal proceedings, i.e., *Edwards v. National Coal Board* and *Marshall v. Gotham Co LTD*, helped create a consistent and clear ALARP definition (Taylor and Israni, 2014).

The first case concerned the death of Mr. Joseph Edwards, whose life was tragically lost due to the fall of a piece of rock from an unsupported section of the National Coal Board's road in No. 2 pit, Marine Colliery's mines (Wales) (Edwards v. National Coal Board, 1949).

As it will be assessed later, the National Coal Board did not comply with safety standards considering that, because of the securing high cost, only half of mines' roadways had been shored up, leading inevitably to this type of accident. Following the decision in this very case, the Court of Appeal coined the term ALARP in 1949 when Judge Asquith LJ gave a definition of the principle and standard of duty. In the judge's words:

"*The construction placed by Lord Atkin on the words 'Reasonably practicable' in Coltness Iron Co v Sharp (1938) seems to me, with respect, right. 'Reasonably practicable' is a narrower term than 'physically possible' and seems to me to imply that a computation must be made by the owner, in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other; and that, if it be shown that there is a gross disproportion between them – the risk being insignificant in relation to the sacrifice – the defendants discharge the onus on them. Moreover, this computation falls to be made by the owner at a point of time anterior to the accident. The questions he has to answer are: (a) What measures are necessary and sufficient to prevent any breach of s 49?; (b) Are these measures reasonably practicable? In the particular type of accident caused by a 'glassy slant', it is admittedly impossible before the event to foresee at all, at what place or in what roadway or in what mine, such an accident would occur. The argument that the owners could and should have made secure the particular roadway in which, as things fell out, the glassy slant declared its presence, without having to make secure every other roadway in which it might have done so, assumes that the owners could by some process of divination, have predicted that the accident was likely to occur in the particular roadway in which it did, rather than elsewhere. But an owner who is not gifted with second sight can make no such prediction; and without it, security against this peril can only be secured by extending similar security measures to all roadways. Only so can he prevent breaches of s 49 due to glassy slants*.".

Moreover, the judge continued:

"*So far, I am inclined to agree with the learned judge. But, like my Lord, I do not think any or any sufficient evidence was adduced as to the relative quantum of risk and sacrifice involved, on the basis either that the mines as a whole, or this particular roadway, should be taken as the unit – a necessary prerequisite to any decision that the defendants have proved the necessary measures impracticable. For these reasons I think the appeal should be allowed*.".

On the other hand, the second case focused on the death of Mr. George William Marshall, a gypsum miner, who was hit by a large piece of the mine's marl roof while working, which costed him his life. The action was brought to the court against the Gotham Company Limited by his widow, Mrs. Marshall, in 1952 (Marshall v Gotham Co Ltd, 1954).

In this case, the tribunal, i.e. the House of Lords, agreed on the unwonted cause of the accident, claiming that the collapse of the roof was caused by a slickenside, an unexpected accident that had not occurred in the defendant's mines for at least 25 years. It is worth noting that although the decision was unanimous, the judges of the court had different opinions on the case.

The latter can be summarized in Lord Oaksey's perspective, who stated that:

"*What is "reasonably practicable" depends upon a consideration whether the time, trouble and expense of the precautions suggested are disproportionate to the risk involved. It is conceded in the present case that it was not reasonably practicable to make the roof secure by timbering, and to have attempted to make it secure by pneumatic props in some places and by leaving it un-mined in others when no slickenside had ever occurred for a period of 20 years was not, in my judgment, reasonably practicable.",* and Lord Reid's perspective, who held that:

"*If a precaution is practicable it must be taken unless in the whole circumstances that would be unreasonable. And as men's lives may be at stake it should not lightly be held that to take a practicable precaution is unreasonable".*

Moreover, Lord Reid as well as Lord Asquith took into consideration the "disproportionate cost test", already used in the *Edwards v National Coal Board* case. By recalling this instrument, Lord Reid clearly accepted that even the high cost of a procedure might be considered sometimes as an umreasonably practicable measure. This approach is clearer in Lord Reid's words:

"Slickenside was a known danger, but there was no more reason to anticipate it or provide against it at the place of the accident than elsewhere in the mine, and a finding that precautions ought to have been adopted at the place of the accident would imply that they ought also to have been adopted generally. I am of opinion that this was not reasonably practicable, and I base my opinion on these factors. The danger was a very rare one. The trouble and expense involved in the use of the precautions, while not prohibitive, would have been considerable. The precautions would not have afforded anything like complete protection against the danger, and their adoption would have had the disadvantage of giving a false sense of security.".

In addition, Lord Keith claimed that:

"there was no general rule or test which could be adopted and that the issue must depend on the particular circumstances of each case".

Lastly, Lord Tucker and Lord Cohen asserted that:

"liability under the statute cannot be ascertained merely by applying the test of common law negligence" (Barret and Howells, 2000), (Act, H. S. W., 1974).

As one can notice, both cases adopted a disproportionate-cost approach to justify the conflict on defendants' duties to take all "reasonably practicable" precautions. Indeed, juries in *Edward* and *Marshall* cases held that the only reason that explained the origin of events had to be traced back to an "unusual geological condition".

3. ALARP in UK and Italy

As mentioned earlier, in 1974 United Kingdom approved the *Health and Safety at Work etc. Act.* In the latter, the well-explained principle of "reasonably practicable" dwells at the center of the regulation, as well as in the laws, acts and guidelines conceived after. One question that arises from the *1974 Health and Safety at Work etc. Act*. concerns the meaning of "reasonably practicable". First of all, it must be clarified that the ALARP principle and the "reasonably practicable" notion can be read as one whole.

Then, it is possible to assert that both aim at lowering as much as possible the probability of risks at work – sort of explained also in Section 2 and 3 of the law, which impose to employers to adopt all the reasonably practicable steps to avoid accidents (HSE, 2001).

Moreover, another issue that must be taken into account regards the criteria used to evaluate a possible violation of the ALARP principle by the employer. Usually, the parameters are based on current standards and the Approved Codes of Practice (ACOP), a fundamental tool with special legal status that helps engineers comply with the law and implement good practices. For instance, if duty-holders are prosecuted for a breach of the health and safety law and it is proved that they have not followed the relevant provisions of the ACOP, a court will find them at fault unless they can show that they have complied with the law in some other way. On the opposite, if engineers comply with the ACOP, they will not find themselves in breach of the law and it will additionally demonstrate that the ALARP principle has been implemented by them (Gilles, 2001).

The Monte Bianco tunnel accident, along with other significant incidents like those at Gotthard and Tauern, serve as crucial case studies showcasing both the application and challenges of the ALARP principle. These accidents spurred intensive scientific and governmental discussions, which led to the adoption of ALARP as a guiding principle for tunnel safety. Importantly, these incidents have highlighted the potential for catastrophic occupational accidents due to tunnel instability, and risks to users from traffic accidents within the tunnels. Risk acceptance criteria, which are integral to ensuring safety and quality in various societal sectors, are typically developed and executed legally and practically within professional communities, informed by their use, judgement, and prevalent values (Engen et al., 2017). This ties into discussions on risk and barrier regulation, audit, investigation, and organizational accidents (Reason, 2016), (Baldwin and Black, 2010). It's crucial to understand how and where ALARP principles are applied both legally and practically across various industries, such as petroleum, nuclear, and petro-chemical. As a result, the implementation of ALARP has extended from a focus solely on occupational safety to include user safety. By integrating the ALARP principle into its legislation, Italy has established mandatory acceptability and tolerability criteria through the Italian Legislative Decree 05 October 2006, n. 264 (Decreto Legislativo n.264, 2006). Duty holders, including those responsible for the safety of users in Italian tunnels, are required to demonstrate their design scenarios' compliance with these criteria, which set the exceedance probability of one fatality in one year at 10^{-1} for acceptability and 10^{-4} for tolerability (Alakbarli et al., 2023). The principles of acceptability and tolerability define the levels of safety that can be unconditionally accepted or conditionally tolerated if further safety improvements aren't feasible. However, the practical implementation of ALARP can be compromised by arbitrary definitions of acceptability and tolerability, and the economic feasibility of achieving safety improvements. If it is demonstrated that spending additional resources to improve safety would result in a negative economic outcome for the operation, it may not be practicable to do so, as stipulated by the ALARP principle. These challenges, as demonstrated in the Monte Bianco case in Section 4 and 5, necessitate a continuous reassessment of safety measures and their effectiveness. As indicated by Judge Asquith's defining judgement of ALARP in Section 2, if the aim of guaranteeing a certain level of safety is not reasonably practicable, the decision must be adjusted. Furthermore, it should also be noted that ALARP plays an important role in tunnel accidents aiming at pushing hazards' limits as low as possible. The only existence of hazards limits does not mean that risk's level must stabilize around the established threshold (Guarascio et al., 2022, 2023). Rather it means that risks must remain under the limit, considering that some users might be more sensible to loss of life hazards than others.

The Quantum of Risk's notion proposed by Lord Asquith in the clear wording of his judgments, has to be a "quantity measurable" in a "specific scale" that in mathematical language is a "probability" times a "Logic indicator function [0,1]" in the case of individual death or an "integer number counting fatalities" in case of multiple fatalities in an accident.

The oldest author (Guarascio, 2021) proposed models for both a continuous real variable "x" and a corresponding discrete integer variable "N", number of fatalities (Guarascio, 2008). The Gu@larp density function is:

$$g[x\_, Gu\_] = (1 - Gu) DiracDelta[x] + if\ [x \geq 1, Gu/x^2, 0] \tag{1}$$

and the corresponding exceedance probability:

$$G(x) = Gu * x^{-1} \tag{2}$$

Here, "G(x)" represents the probability of the variable "x" exceeding a certain value. It is calculated using the parameter "Gu" and the inverse of "x".

A discrete function is used to represent the risk of death for individuals, considering only integer values. This function corresponds to the specific scenario and quantifies the risk associated with different numbers of fatalities:

$$Gu(N) = Gu * N^{-1} \tag{3}$$

Based upon Equation (3) appropriate model can be developed in order to describe the distribution of:

- Risk Quanta of Design Scenario
- The individual Risk quantum in each scenario.

4. Investigation of the Monte Bianco tunnel on March 24, 1999

In the investigating of the Monte Bianco tunnel accident, the aim was to determine what caused the catastrophe and to understand the factors that contributed to its severity. Four forensic investigation teams were deployed to the field to meticulously examine the events, encountering significant challenges related to the condition of human remains and environmental hazards (Baccard et al., 1999). Despite this context, a rigorous methodology in the collection of human remains allowed for positive results in subsequent forensic identification.

The main issue that engineers and forensic experts had to face concerned what caused the fire in the truck. They traced the entire journey of the truck as it was approaching the tunnel. This was where problems could first arise, trucks often overheated on long climbs up to the tunnel entrance. One of the possible causes of the fire might have been a collapse of the FH12 engine. However, despite the likelihood of this hypothesis, forensic engineers excluded any possibilities of such an event, stating that no traces were found of overheating.

Then a turning point occurred, inspectors found particles within the engine likely stemming from an air filter which might have burned earlier than the accident. In spite of this, many doubts surrounded this theory. While reproducing the accident, investigators assumed that the minor fire could have been caused by a cigarette butt entering the air filter.

However, how did this small fire turn into a large conflagration? Investigators suppose that the accident was generated by a small fire inside of an engine under the cabin before the entrance of the truck to the tunnel. In fact, according to experts, the truck entered 14 minutes later in the tunnel, longer after the main fire already started and Mr. Degrave (the driver of the burning truck) decided to pull over the truck due to the smoke. Experts, using an example about an avoided accident by a truck driver in the alpine tunnel, explained how it is possible for a truck to start a fire whenever drivers decide to slow down or stop. This can be explained by the fact that when a truck keeps moving, the movement of air in the tunnel prevents the fire from spreading considering that oxygen contributing to the fire decreases. On the opposite, if truck stops, oxygen will spread faster.

Another doubt regards how the fire increased so fast. According to tunnel expert, the truck was carrying only half a tank of diesel (550 liters) (Lacroix, 2001). The suggested fire size for tunnel safety design used to be 30 MW, but in 2011, it was increased to a maximum of 200 MW for Heavy Goods Vehicles (HGVs). Experts also examined the cargo, which included seemingly harmless items like margarine and flour. Although not classified as dangerous goods at the time, margarine is now rated as a flammable material (NFPA 704, 2022). A test with a ton of margarine and the insulated material covering the trailer confirmed its high flammability within 2 minutes of exposure to fire (Campbell and Vaughan, 2004).

According to the legal scheme, several tests had to be piloted after the Monte Bianco accident. Another test was conducted with a real HGV vehicle also transporting 400 kg of margarine and using a 1.5 m/s ventilation, as it is in the Monte Bianco tunnel. Subsequently, after 40 minutes, a peak HRR of 23 MW was recorded. In addition, it must be mentioned that the experiment was implemented after removing tires and fuel tank to limit the peak HRR (Brousse et al., 2001). The total calorific energy value of the truck and trailer with its goods amounted to 76 GJ during testing, whereas this value is comparable to the estimated value of 500-600 GJ during the real fire (Ingason et al., 2014). One can notice that during the test, also the asphalt pavement alterations were analyzed; in fact, it was estimated that a burning block of asphalt long 1.2 km can release the same calorific energy as 85 cars burning at the same time or 12 trucks (Faure et al., 2007).

Nevertheless, two questions still remain open. First, how is it possible that an apparent harmless load of flour and margarine gave rise to a 300 MW fire. Secondly, what role did the 14 trucks behind the burning truck play in the accident, especially given the impact of the few trucks burning on the asphalt. Noteworthy it is to remind that the latter starts to burn at a temperature of about 500 °C (in the Monte Bianco the recorded temperature was over 1000°). Regarding the first question, it can be noticed that the first truck was actually followed by a second truck carrying also margarine, so this can explain the high quantity of polyethylene that combined firepower.

Addressing to the second question, we consider how fire spread between distant vehicles, despite the fire not being the direct cause of fatalities. Four possibilities were considered: Convection, Burning Liquids, Flame and Radiation, and Pavement Combustion, but none could be definitively proven.

However, the investigation highlighted that the smoke, not the fire, was the lethal element. Within 7 minutes, the smoke, containing cyanide, traveled 800 meters at 4.5 m/s, causing sudden vision loss up to half a meter. This rapid and deadly smoke dissemination made it impossible for anyone in the French half of the tunnel to escape.

Investigators couldn't explain why smoke swiftly enveloped vehicles and flowed from Italy to France, contrary to normal tunnel air movement. They proposed changing weather conditions as a potential cause, as unusual winds from Italy to France occur about 20 days per year. However, they also explored other factors, such as the activation of large fans in the tunnel's plant rooms. These fans could supply or evacuate air from an under-road duct. Four supply air ducts each provided 75 m^3/s of fresh air, with a fifth duct later adapted to increase fresh air supply (Voeltzel and Dix, 2004). Typically, these ducts supply air, but in fires, duct five is supposed to evacuate smoke. Did the operators follow the correct emergency procedure? Investigations revealed that an Italian operator inappropriately supplied fresh air instead of extracting it during the incident, contradicting protocol. Despite the potential consequences, the team proceeded, believing it was the best immediate solution.

Among the factors that might have contributed to the increase of the victims' number, there is the traffic lights' malfunctioning. As a matter of fact, traffic signals are present at the entrance of the tunnel and every 1200 m. At 10:55 am the signals turned red on the French side and at 10:56 am on the Italian side as well. What make experts hypothesize the malfunctioning is the fact that if lights had been red, drivers would have indeed stopped. Since this action did not happen, the only probable explanation is that either the traffic lights did not work, or the drivers ignored it. However, this remains only a hypothesis, conditional on the fact that traffic light control systems did not activate.

The accident that took place on 24 March 1999 provided changes that will be able to save lives in the future and forced improvements to the safety requirements established in 1985 but ignored until that moment. The accident led to the adoption of a cascade of safety measures in the Monte Bianco tunnel. Nowadays, speed limits and minimum distances between vehicles are strictly enforced.

In 2001, the French Gendarmerie disclosed a critical investigation detail. They found that French and Italian companies, responsible for tunnel safety, prioritized profit over safety. The French firm, ATMB, particularly disregarded safety rules about truck quantity and vehicle distance within the tunnel. Investigations revealed ATMB's profits were approximately 91.4% of their total earnings, while their safety budget was almost negligible. The inquired proceeded long enough to find conspicuous proof to be presented before the court in order to find the culprits in the Monte Bianco case.

5. Legal aspect of the Monte Bianco tunnel case

On February 1, 2005, after a 57-day trial, the Bonneville court gave its final verdict in the Monte Bianco tunnel fire case on March 24, 1999, in which 39 people died. 16 people, including 12 natural and 4 legal entities, were brought to court under the article "Manslaughter as a result of recklessness, carelessness, inattention, negligence or breach of security obligation"

On 27 July 2005, "the truth no longer has a gray area, and we can conclude that this catastrophe could have been avoided", the presiding judge Renaud Le Breton de Vannoise said in the court, before reading the verdict, a 630-page document, in front of most of the defendants and dozens of civic parties (Le Moniteur, 2005). In Bonneville Court, thirteen of the sixteen defendants were found guilty and the charges against the three defendants were dropped, some received sentences ranging from fines to suspended prison terms of up to six months.

Later, on 19 February 2007, in the Chambery Court of Appeal, Michel Charlet was acquitted and the driver, Gilbert Degrave, was granted an amnesty. On appeal, French tunnel security officer Gérard Roncoli's sentence was upheld.

In the three years following the accident, involved firms have been engaged in modernizing and restoring the tunnel, adopting solutions that are nowadays considered a worldwide model and that have been included in the European directive on "minimum safety requirements for tunnels in the Trans-European Road Network" edited in 2004. Since the re-opening of the tunnel in 2002, the structure is now administrated by one single European company, GEIE-TMB, established according to the decision of the two former companies engaged with the tunnel safety, the Italian SITMB and the French ATMB. Following in 2006, a new agreement between the Italian and French authorities is reached, which replaced the old agreement established in 1953 and provided a framework on companies' requirements until 1950. The same agreement has been officially sanctioned by the two governments in 2008, with the Italian law No.166/2007 and the French Law No.575/2008 (GEIE-TMB, 2018).

6. Conclusions

During our investigation, we determined that the severity of the fire in the Monte Bianco tunnel resulted not from a single factor but from a combination: protocol breaches, inadequate personnel training, deficient tunnel safety systems, delayed maintenance, weather conditions, inconsistent ventilation at both ends of the tunnel, and the highly flammable nature of the trailer insulated with polyurethane foam and the cargo loaded with hazardous materials, which at the time were not considered hazardous material.

From the case, it should be borne in mind that making thoughtful engineering decisions, assessing risks and uncertainties lay at the heart of all standards and guidelines. The forensic and scientific investigations carried out show that, the level of risk inherent in the inquired Monte Bianco tunnel must be considered not acceptable for the specified ALARP principle. Now we should ask ourselves "Is another Monte Bianco disaster possible anywhere in the world?". The answer is yes, it is and perhaps it's just a matter of time. However, until this happens, millions of vehicles continue to pass safely through traffic tunnels every day and we should be aware that "as low as reasonably practicable" is about weighing a risk against the problem, time and money required to control it. Therefore, ALARP defines the level at which we expect to see risks being managed in tunnels and it is the way to define the legal obligation to take all reasonable practical measures to mitigate and manage as for instance has been established in Italy by the Italian Legislative Decree 05 October 2006, No. 264 and Gu@larp model has been developed.

This study provides an important example for learning from accidents such as the Monte Bianco tunnel disaster and applying the lessons learned to future projects. By following the rules - and standards - established for road tunnels and implementing the ALARP concept, the safety of millions of vehicles passing through tunnels can be ensured. Furthermore, the use of risk quantification methods, such as the Risk Quantum Gu@larp, can help identify scenarios with high risk quantum and allow focused efforts to reduce those risks. This approach can be applied across various sectors, not just road tunnels, and provide valuable evidence in court proceedings to demonstrate proactive risk management measures.

By integrating mathematical models and risk quantification techniques into safety assessments and decision-making processes, stakeholders can enhance safety measures and reduce the potential for disasters and catastrophics. This proactive approach aligns with the principles of ALARP and contributes to a safer environment for all.

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