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Quality is safety
Kvalitet je bezbednost

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Abstract
Welding alters the engineered properties of a material, affecting irrevocable changes to the metallurgical structure and mechanical characteristics due to the addition of energy, to combine two materials into one. As a fabrication process, this method has been used since the early part of the 20th century and has become the basic means to construct and build most of the industries required for modern society. Almost since the beginning, in the 1930s, there was the recognition that welding codes or standards were required for higher quality weld metal. This understanding has expanded to include and manage the parent material changes in the heat-affected zone as well. Most codes and standards in use, has been influenced by catastrophic failures and therefore provide minimum requirements to achieve suitable welds that will result in safe service. In addition, the control of weld properties and therefore the integrity of a welded component to function safely, is managed in part by quality control. Weld safety, however, is more than this, and should entail the whole process from design to delivery and is achieved by a systematic weld quality management system, implemented ethically. This paper reviews the influence of some catastrophic weld failures, and aims to show how ethics, weld quality management, and engineering interact to ensure weld safety.

Rezime
Zavarivanje menja inženjerske osobine materijala, koje utiču na neopozive promene metalurške strukture i mehaničkih karakteristika usled unosa energije, radi kombinovanja dva materijala u jedan. Kao proces izrade, ova metoda je korišćena od početka 20. veka i postala je osnovno sredstvo za konstruisanje i izradu u većini industrija neophodnih za savremeno društvo. Skoro od početka, 1930-ih, uočeno je da su pravila ili standardi za zavarivanje, potrebni za kvalitetniji metal šava. Ovo shvatanje je dalje prošireno tako da uključuje i upravlja promenama osnovnog materijala u zoni uticaja toplote. Na većinu pravila i standarda u upotrebi uticali su katastrofalni propusti i stoga obezbeđuju minimalne zahteve za postizanje odgovarajućih zavarenih spojeva koji će rezultovati sigurnim radom. Pored toga, kontrola karakteristika zavarivanja i samim tim i integriteta zavarene komponente radi bezbednog rada, delimično se upravlja kontrolom kvaliteta. Bezbednost zavarivanja, međutim, je više od ovoga i trebalo bi da obuhvati čitav proces od projekta do isporuke i postiže se sistematičnim menadžmentom kvalitetom zavarivanja, koji se etički primjenjuje. U radu se analizira uticaj nekih katastrofalnih propusta zavarivanja i ima za cilj da pokaže kako etika, menadžment kvalitetom zavarivanja i inženjering zajednički deluju na obezbeđenje bezbednog zavarivanja.

1.Introduction
Welding is defined in many places, and in the Australian Standards it is described as a "joint in material, produced by means of heat or pressure, or both, in such a way that there is continuity in the nature of the metal between these parts."[1].
It encompasses a range of processes developed over the last century that have been commercially used since the early 1900s [2].

1.Uvod
Zavarivanje je definisano na mnogim mestima, u australijskim standardima opisano je kao "spoj u materijalu, proizveden toplotom ili pritiskom, ili oba, na takav način da postoji kontinuitet u prirodi metala između tih delova." [1].
Ono obuhvata niz procesa razvijenih tokom prošlog veka koji su komercijalno korišćeni od početka 1900-ih godina [2].

While its usefulness and versatility has been the foundation for many technological advances, the application of pressure or heat to achieve coalescence changes the engineered structure of the parent materials. Therefore, it may be a high risk process that requires careful management, since it can affect the safety of the component or structure it is applied to.
When selecting the appropriate weld quality management requirements, the application requirements determine the design code or standard, which sets materials, fabrication and inspection specifics to economically and safely deliver the required technology or product.
The role of the engineer is to respond to a perceived need by building or creating something to a set of guidelines (the relevant design code or standard) that performs a certain function [3]. It is imperative that the device, system, or component should perform its function without failure. However, since everything must eventually fail in some way, this means that a desired level of performance is needed. Therefore, it is the responsibility of the engineer to design in such a way as to avoid catastrophic failure that could result in the loss of property, damage to the environment and injury or loss of life [3].
A traditional design methodology is shown in Figure 1.

Iako je njegova korisnost i svestranost bila temelj mnogih tehnoloških napredaka, primena pritiska ili toplote za postizanje koalesencentnih promena strukture osnovnih materijala. Stoga, to može biti proces visokog rizika koji zahteva brižljiv menadžment, jer utiče na bezbednost komponente ili konstrukcije na kojoj se primjenjuje.
Prilikom izbora odgovarajućih zahteva za menadžment kvalitetom zavarivanja, zahtevi primene određuju pravilo ili standard pri projektovanju, koji podešava materijale, izradu i specifične inspekcije kako bi se ekonomično i bezbedno isporučila potrebna tehnologija ili proizvod.
Uloga inženjera je da odgovori na uočene potrebe za izgradnjom ili kreiranjem niza smernica (odgovarajuće projektno pravilo ili standard) koji obavlja određenu funkciju [3]. Neophodno je da uređaj, sistem ili komponenta izvrše svoju funkciju bez nedostataka. Međutim, s obzirom da sve eventualno može da propadne na neki način, to znači da je potreban željeni nivo osobina. Zbog toga, inženjer je odgovoran da projektuje na način kojim bi se izbegao kritični otkaz koji bi mogao dovesti do gubitka imovine, oštećenja životne sredine i povređivanja ljudi ili gubitka života [3].
Tradicionalna metodologija projektovanja prikazana je na slici 1.

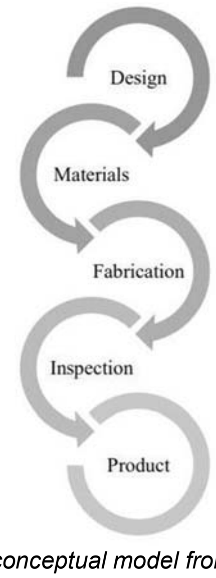

Figure 1. *Common conceptual model from design to product [5]*
Slika 1. *Uobičajeni konceptualni model od projekta do proizvoda [5]*

Here, the design usually provides input about dimensions and materials, but seldom welding process. When referring to a standard or code, the reference is mostly general and many aspects are left to the fabrication and inspection function to make engineering decisions.
This may lead to decisions being made during fabrication and inspection that ultimately affect the sought level of performance of the components or

Ovde, projekat obično nudi ulazne podatke o dimenzijama i materijalima, ali retko postupak zavarivanja. Kada se govori o standardu ili pravilu, referenca je uglavnom opšta, a mnogi aspekti su prepušteni izradi i inspekcijskoj funkciji za donošenje inženjerskih odluka.
Ovo može dovesti do donošenja odluka prilikom izrade i inspekcije koje na kraju utiču na traženi nivo performansi komponenti ili konstrukcija, što će,

structures, which, as some of the case studies presented will show, resulted in catastrophic failure. Analyses done on catastrophic failures have identified factors, flaws and failures in engineering that resulted in these events [3].
While the design and therefore engineering practices have fundamental influences on the safety and performance of components and structures, during fabrication the safe application of welding relies heavily on many disciplines, including welding inspection.
The role of the welding inspector is also examined, and illustrated by looking at the consequences of poor inspection ethics and the importance of accurate inspection data.
This article aims to show how an integrated weld quality management process is required to prevent catastrophic failures and achieve safe welds, from design to inspection during fabrication, as well as in-service inspection during maintenance activities.

2. Quality Management

6.1. Why quality management is required for welding

The old expression: “Horses for courses” has been used to describe the fact that not all welding operations require the same level of intervention or management to achieve a safe outcome [13]. There are significantly different requirements for a basic weld to hold a small bracket in place to the complex requirements of a system under high temperature and pressure, where the catastrophic failure of the weld could allow the uncontrolled release of energy, i.e. explosion.
Since welding fundamentally changes the carefully engineered properties of the material when it is welded, the application determines the safety level needed, which will determine the applicable risk reduction to be implemented that therefore influences the quality requirements, as shown in Figure 2. And many times at this part of the discussion, the question of cost is raised, and usually in terms of the cost of implementing quality management.
But the pertinent discussion should not just be about the cost of quality management, but rather the cost of catastrophic failure. This is the true cost to benefit analysis that is indispensable for the safe application of welding.

6.2. Quality management historically

But is quality management a new phenomenon, a modern day buzz word, excessively used? The fact is that quality management has been around for centuries, and can be traced back to the Middle Ages [4] where a master craftsman inspected work completed by apprentices and journeyman before

kako će pokazati neke od studija slučaja, dovesti do kritičnog otkaza. Analize koje su sprovedene na kritičnim otkazima identifikovale su faktore, greške i propuste u inženjeringu koje su rezultovale ovim događajima [3].
Iako projektne i stoga inženjerske prakse imaju fundamentalne uticaje na sigurnost i performanse komponenti i konstrukcija, prilikom izrade, sigurna primena zavarivanja se oslanja na mnoge discipline, uključujući inspekciju zavarivanja.
Takođe je ispitana uloga inspektora za zavarivanje i ilustrovana sagledavanjem posledica loše inspekcijske etike i važnosti preciznih podataka inspekcije.
Ovaj članak ima za cilj da pokaže kako je neophodan integralni proces menadžmenta kvalitetom zavarivanja kako bi se sprečill kritični otkazi i postiglo bezbedno zavarivanje, od projekta do inspekcije tokom izrade, kao i inspekcija tokom eksploatacije kao i tokom održavanja.

2. Menadžment kvalitetom

6.1. Zašto je potreban menadžment kvalitetom u zavarivanju

Stari izraz: "različitim ljudima pašu različite stvari" se koristi da opiše činjenicu da za sve operacije zavarivanja nije potreban isti stepen intervenisanja ili upravljanja kako bi se postigao siguran ishod [13]. Postoje značajno različiti zahtevi za osnovni zavareni spoj koji drži mali nosač na mestu prema složenim zahtevima sistema pod visokom temperaturom i pritiskom, gde bi katastrofalni otkaz zavarenog spoja doveo do nekontrolisanog oslobađanja energije, tj. eksplozije.
Pošto zavarivanje fundamentalno menja pažljive konstruktivne osobine materijala kada se zavaruju, primena određuje potrebni nivo sigurnosti, koji će odrediti primenljivo smanjenje rizika koje će se implementirati, što utiče na zahteve kvaliteta, kao što je prikazano na slici 2. I mnogo puta u ovom delu diskusije postavljeno je pitanje troškova, a obično u smislu troškova implementacije menadžmenta kvalitetom.
Ali relevantna diskusija ne bi trebalo da bude samo o troškovima menadžmenta kvalitetom, nego o ceni kritičnog otkaza. Ovo je prava analiza troškova koja je neophodna za bezbednu primenu zavarivanja.

6.2 Menadžment kvalitetom istorijski

Ali da li je menadžment kvalitetom novi fenomen, reč koja se danas previše čuje i koristi?
Činjenica je da je menadžment kvalitetom postojao vekovima, a može se pratiti u srednjem veku [4], gde bi majstor zanatlija obavio inspekciju radova koje su završili šegrti i kalfe pre nego što bi gotove

providing the finished products to clients. This ensured quality standards were met, that the finished products and all the required aspects were suitable for use; and it made certain that the client was satisfied.

proizvode dali klijentima. Ovim je obezbeđeno da su standardi kvaliteta ispunjeni, da su gotovi proizvodi i svi potrebni aspekti bili pogodni za upotrebu; i sigurno je da je klijent bio zadovoljan.

Figure 2. *How application determines quality requirements*
Slika 2. *Kako primena određuje zahteve kvaliteta*

During the 1920s, quality management systems, as we know them today, started to emerge, where there the focus still remained on the end product and quality control was determined by final inspections.

This started to change in the 1940s, when companies continued to experience difficulties in following through with quality standards, which precipitated a change with respect to inspections. These were now carried out by production personnel during the fabrication process at specific intervals, thereby preventing problems in the end product through early detection [4]. Therefore, the reduction in defective parts resulting in cost savings, and, possibly, in an increase in safety.

3. Factors, Flaws and failures contributing to catastrophic failure

Catastrophic failure is defined by the Centre for Chemical Process Safety [6] as “A failure which is both sudden and causes termination of one or more fundamental functions”. According to the Oxford definition [7], catastrophic is defined as something that causes “sudden great damage or suffering”. So, it is a sudden failure where termination of one or more fundamental functions causes great damage or suffering.

Since the aim of engineering is to prevent catastrophic failure when creating new structures or components, or maintaining existing ones, it follows that there could be factors, flaws and failures contributing to the primary causes of engineering disasters [3]. These can be grouped as human factors, design flaws, materials failures (which would include weld failures) or extreme conditions and environments. Often, these occur in combination.

Tokom 1920-ih godina, sistemi menadžmenta kvalitetom, kako ih danas znamo, počeli su da se pojavljuju, gde je fokus i dalje ostao na krajnjem proizvodu, a kontrola kvaliteta određena je završnim inspekcijama.

Ovo je počelo da se menja u četrdesetim godinama, kada su kompanije nastavile da se suočavaju sa poteškoćama u sprovođenju standarda kvaliteta, što je dovelo do promene u pogledu inspekcije. Ovo je sada sprovođeno od strane proizvodnog osoblja tokom procesa proizvodnje u određenim intervalima, čime se sprečavaju problemi u krajnjem proizvodu kroz rano otkrivanje [4]. Zbog toga smanjenje defektnih delova rezultuje uštedom troškova i, eventualno, povećanjem sigurnosti.

3. Faktori, mane i propusti koji doprinose kritičnom otkazu

Kritični otkaz je definisan od strane Centra za bezbednost hemijskih procesa [6] kao "otkaz” koji je iznenadan i uzrokuje prekid jedne ili više osnovnih funkcija". Prema definiciji Oksforda [7], kritično se definiše kao nešto što uzrokuje "iznenadnu veliku štetu ili stradanje". Dakle, iznenadni otkaz je termin za kraj jedne ili više osnovnih funkcija što izaziva veliku štetu ili stradanje.

Pošto je cilj inženjerstva da spreči kritični otkaz pri stvaranju novih konstrukcija ili komponenti ili održavanja postojećih, sledi da bi moglo biti faktora, mana i propusta koji bi doprineli primarnim uzrocima tehničkih katastrofa [3]. One se mogu grupisati kao ljudski faktori, nedostaci u projektu, propusti u materijalima (koji bi uključivali grešku u zavarivanju) ili ekstremne uslove i okruženje. Često se one javljaju u kombinaciji.

Interestingly, it was shown [3] that human factors included both ethical failure and accidents, and it included unethical practices under design flaws, thereby concluding that engineering ethics was found to be one of the root causes of engineering disasters that resulted in catastrophic failure. Therefore, it was proposed that engineers as professionals have a responsibility to clients, employers and the general public to perform their duties in as conscientious a manner as possible. This goes beyond just acting within the bounds of the law [3], and requires avoiding conflict of interest, not misrepresenting knowledge and accepting work outside their area of expertise, while acting in the best interest of society and fulfilling the terms of the contract in a professional manner. In light of this, it is proposed that ethical engineering practice to prevent failure can also be extended not just to fabrication, but welding inspection as well.

4. Case study: Unethical welding inspection

In 2009, a welding inspector at Northrop Grumman's Virginia shipyard in the USA, reported a fellow inspector for signing off on ship welds without inspecting them [8]. The admission of wrong doing by the inspector resulted in a very serious situation, since he was responsible for over 10 000 welds on 8 Virginia class nuclear fast attack submarines and a new nuclear aircraft carrier.

It was also found that 10% of the submarine welds affected joints on critical components and hull integrity. Equally alarming was the inclusion of similar issues at General Dynamic Boat in 2010, at their Rhode Island shipyard. They were a sub-building partner of Northrop Grumman, and this highlighted that the failure of inspection ethics was not an isolated event, which precipitated a costly in-depth review and welding re-inspection program. While the Navy review of Dynamic Boat provided some measure of assurance since it indicated that there was a low probability of improper welds, the additional time and cost to validate safety critical welds added costs that were completely unnecessary.

The question then is what can contribute to unethical welding inspection practices?

5. Importance of accurate weld inspection data

It may be beneficial to conduct a formal industry survey regarding welding inspection expectations, since numerous discussions within Australia with asset managers, fabrication and maintenance companies and welding inspectors highlighted that there may be conflicting requirements affecting inspection practices. During some of these conversations, a "good" welding inspector was seen as someone not finding too many issues and

Interesantno je pokazano [3] da su ljudski faktori uključivali i etički neuspeh i nesreće, a uključivao je i neetičku praksu u projektnim propustima, čime se zaključuje da je inženjerska etika utvrđena kao jedan od osnovnih uzroka inženjerskih katastrofa koji su rezultovali kritičnim otkazima. Zbog toga je predloženo da inženjeri kao stručnjaci imaju odgovornost prema klijentima, poslodavcima i široj javnosti da svoje poslove obave na što savesniji način. Ovo prevazilazi samo delovanje unutar granica zakona [3] i zahteva izbegavanje sukoba interesa, a ne pogrešno predstavljanje znanja i prihvatanje posla izvan njihovog stručnog područja, istovremeno delujući u najboljem interesu društva i ispunjavanju uslova ugovora na profesionalan način. U svetlu ovoga, predlaže se da etička inženjerska praksa za sprečavanje neuspeha proširi ne samo na izradu, već i na zavarivanje.

4. Studija slučaja: neetička inspekcija zavarivanja

Godine 2009, inspektor za zavarivanje u brodogradilištu Northrop Grumman u Virdžiniji u SAD-u prijavio je kolegu inspektora za odjavljivanje sa brodograđevinskog zavarivanja bez inspekcije [8]. Pogrešan postupak od strane inspektora doveo je do veoma ozbiljne situacije, pošto je bio odgovoran za više od 10 000 zavarenih spojeva na 8 brzih nuklearnih podmornica Virginia klase i novi nuklearni nosač aviona.

Takođe je utvrđeno da 10% podmorničkih zavarenih spojeva su spojevi koji utiču na kritične komponente i integritet trupa. Podjednako alarmantno je bilo uključivanje sličnih problema na General Dinamic Boat 2010. godine u brodogradilištu u Rhode Islandu. Oni su bili partner za izgradnju Northrop Grummana, i to je naglasilo da neuspeh inspekcije nije bila izolovani događaj, što je dovelo do skupog programa dubinske kontrole i programa za ponovnu inspekciju zavarivanja. Dok je mornarički pregled Dinamičkog broda davao određenu meru sigurnosti, pošto je ukazao na to da je postojala mala verovatnoća nepravilnog zavarivanja, dodatno vreme i troškovi za validaciju sigurnosno kritičnih zavarenih spojeva stvaraju troškove koji su potpuno nepotrebni.

Pitanje je onda šta može doprineti neetičkim postupcima inspekcije zavarivanja?

5. Značaj preciznih podataka o inspekciji zavarenog spoja

Može biti korisno obaviti formalno istraživanje industrije o očekivanjima vezanim za inspekciju zavarivanja, pošto su brojni razgovori u Australiji sa menadžerima sredstava, proizvodnje i održavanja i inspektorima za zavarivanje pokazali da mogu postojati konfliktni zahtevi koji utiču na praksu inspekcije. Tokom nekih od ovih razgovora, "dobar" inspektor therefore not interrupting production targets or project deadlines negatively.

However, an industry survey done by TWI in 2011 on weld repair rates [9] showed that rates in the Power and Oil and Gas sectors were typically 1 to 3%, but with peaks up to 25% in specific locations with exceptional values up to 55%. Peak repair rates were observed for root runs, fillet welds and areas with limited access. Both these sectors have piping systems, onshore piping and pressure vessels, with the Oil and Gas sector including off-shore structures and pipelines. The factors affecting weld repair rates are shown in Figure 3. The question then is what can contribute to unethical welding inspection practices?

za zavarivanje je smatran neko ko ne pronalazi previše problema, pa samim tim ne prekida ciljeve proizvodnje ili projektne rokove.

Međutim, istraživanje industrije koje je uradio TWI u 2011. godini o stopama popravki zavarenih spojeva [9] pokazalo je da su stope u sektoru snabdevanja naftom i gasom obično od 1 do 3%, ali sa skokovima do 25% na određenim lokacijama sa izuzetnim vrednostima do 55%. Najveći obim popravki je zabeležen kod korenih zavara, ugaonih zavarenih spojeva i područja sa ograničenim pristupom. Oba ova sektora imaju sisteme cevovoda, kopnene cevovode i posude pod pritiskom, sa sektorom nafte i gasa, uključujući i podmorske konstrukcije i cevovode. Faktori koji utiču na popravke zavrenih spojeva su prikazani na slici 3. Pitanje je onda šta može doprineti neetičkim postupcima inspekcije zavarivanja?

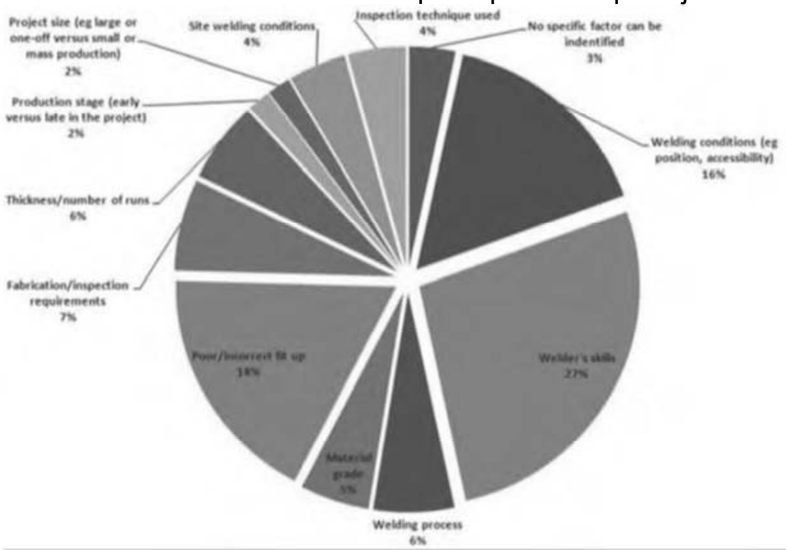

Figure 3. *Factors affecting weld repair rates [9]*
Slika 3. *Faktori koji utiču na popravke zavarenih spojeva [9]*

The main contributing factors affecting weld repair rates, listed in descending order, are:

- Welder's skills;
- Poor or incorrect fit up;
- Welding conditions, such as position and accessibility;
- Fabrication or inspection requirements;
- Thickness or number of runs;
- Welding process;
- Material grade;
- Site welding conditions
- Inspection technique used; or
- Minor contributions (< 3% each) from production stage, project size or no specific factor identified

Therefore, a professional welding inspector, acting ethically by fulfilling their responsibility to their employer, client and the general public can identify 93% of listed factors during the fabrication or maintenance welding activities. So, the question

Glavni faktori koji utiču na popravke zavarenih spojeva, navedeni u padajućem redosledu, su:

- Veštine zavarivača;
- loše ili nepravilno prilagođavanje;
- uslovi zavarivanja, kao što su položaj i pristupačnost;
- zahtevi za izradu ili inspekciju;
- debljina ili broj slojeva (prolaza);
- postupak zavarivanja;
- klasa materijala;
- uslovi za zavarivanje na terenu (lokacije)
- korišćena tehnika inspekcije;
- ili manji doprinosi (< 3% svaka) iz faze proizvodnje, veličine projekta ili nespecifični faktori

Zbog toga, profesionalni inspektor za zavarivanje, etički postupajući ispunjavanjem svoje odgovornosti prema svom poslodavcu, klijentu i široj javnosti, može identifikovati 93% navedenih faktora u toku svog rada tokom proizvodnje ili održavanja. Dakle, then should be: "Do you want the welding inspector to tell you what you want to hear, or what you need to hear?"

6. Consequences of poor engineering and inspection ethics

If poor design, fabrication and inspection ethics occur, what could the consequences be? To answer this, three additional case studies will be considered.

6.3. Case study: Weld failures in lifting and pressure equipment – Australia 2000 and 2005

An industry alert was issued in 2000, and updated in 2005, by WorkSafe Victoria, Australia with a warning that "weld failure of industrial equipment could cause serious injuries in workplaces", since a number of incidents occurred where lifting equipment and pressure equipment failed that resulted in serious injuries and fatalities [10].

The listed contributing factors, either individually or in combination, resulted in events that prompted the alert. They fell in two categories, namely engineering deficiencies and inspection deficiencies.

The engineering deficiencies during design were:

• The stresses exerted on welds were not fully analysed in the design, alteration or repair of the equipment; and

• Incorrect specification of the type, size, composition and location of the welds, and incorrect specification of the materials of construction in the design, alteration or repair of the equipment.

The inspection deficiencies during fabrication and inspection were:

• Poor quality control of the welding process;

• Using welders without adequate skills to carry out the welding; and

• Inadequate inspection and testing to detect any weld deficiency during the fabrication of the equipment or during the service life of the equipment.

This highlighted that insufficient material and welding engineering specification in design or during modifications requiring design changes, can result in catastrophic failure, which may be exacerbated by poor fabrication and inspection practices.

Some may argue that this comes from lack of knowledge and understanding of the requirements in the Australian Standards. The counter argument can be made that this harkens back to the definition of engineering ethics provided in the Introduction to not act outside the area of knowledge and competence, underscoring the fact that ignorance of the standards and regulations cannot be used as an excuse.

pitanje bi trebalo da bude: "Da li želite da vam inspektor za zavarivanje kaže šta želite da čujete ili šta treba da čujete?"

6. Posledice loše inženjerske i inspekcijske etike

Ako se desi loša konstrukcija, etika izrade i inspekcije, kakve bi bile posledice? Da bismo odgovorili na ovo, biće razmatrane još tri studije slučaja

6.3. Studija slučaja: neuspešni zavareni spojevi u opremi za podizanje i pod pritiskom - Australija 2000 i 2005

Industrijsko upozorenje objavljeno je 2000. godine, a WorkSafe Victoria iz Australije je 2005. izdao upozorenje da "neuspešno zavarivanja industrijske opreme može prouzrokovati ozbiljne povrede na radnim mestima", jer je došlo do velikog broja incidenata gde oprema za podizanje i oprema pod pritiskom nije izdržala opterećenja što je dovelo do ozbiljnih povreda i smrtnih slučajeva [10].

Navedeni faktori doprinosa, pojedinačno ili u kombinaciji, rezultovali su događajima koji su izazvali upozorenje. Spadaju u dve kategorije, odnosno inženjerski nedostaci i nedostaci inspekcije

Inženjerski nedostaci tokom projektovanja bili su:

• Naponi koji deluju na zavarene spojeve nisu bili u potpunosti analizirani u projektovanju, izmeni ili popravci opreme; i

• Pogrešne specifikacije tipa, veličine, sastava i lokacije zavarenih spojeva i pogrešne specifikacije materijala za konstrukciju pri projektovanju, izmeni ili popravci opreme.

Inspekcijski nedostaci tokom izrade i inspekcije bili su:

• loša kontrola kvaliteta postupka zavarivanja;

• korišćenje zavarivača bez adekvatnih veština za obavljanje zavarivanja; i

• neadekvatna kontrola i ispitivanje radi otkrivanja nedostatka zavarenih spojeva tokom izrade opreme ili tokom upotrebe opreme

Ovo je naglasilo da nedovoljna specifikacija materijala i specifikacija zavarivanja u projektu ili prilikom modifikacija koje zahtevaju izmene u projektu, može dovesti do kritičnog otkaza, što može biti pogoršano lošim postupcima izrade i inspekcije.

Neki mogu tvrditi da ovo potiče od nedostatka znanja i razumevanja zahteva u australijskim standardima. Može se izvesti kontra argument jer ovo upućuje na definiciju inženjerske etike koja je predviđena u uvodu t.j. da ne deluje izvan područja znanja i kompetencija, naglašavajući činjenicu da se ignorisanje standarda i propisa ne može koristiti kao izgovor.

6.4. Case study: Petrobas P-36 – Brazil 2001

The National Aeronautics and Space Administration (NASA) in the USA has a publication called Systems Failure Case Studies where they take an in-depth look at a particular topic or situation. In a review of the Petrobas P-36 oil rig that sank on 20 March 2001, published in October 2008, direct and indirect causes of the disaster were identified [11].

The direct cause was attributed to a leakage of volatile fluids that burst a shut-down emergency drain tank causing a violent chain of events, resulting in 11 fatalities and the complete loss of the oil rig. The indirect, underlying causes were a combination of a corporate focus on cost-cutting over safety, poor design of individual parts with regards to a system safety context, component failure without sufficient back-ups and lack of training and communication.

Petrobas executives implemented “aggressive and innovative” cost cutting during the design and production of the P-36 production facilities, while they “extolled that the project successfully rejected the established constricting and negative influences of prescriptive engineering, onerous quality requirements, and outdated concepts of inspection and client control” and that the “elimination of these unnecessary strait jackets” was delivering superior financial performance” [11]. Their statements did not include what analyses were done to determine how these innovations affected safety, showing how corporate culture can be a contributing factor in catastrophic failures.

6.5. Case study: Alexander L Kielland – Norway 1980

The Alexander L Kielland platform capsized on 27 March 1980 resulting in 123 fatalities. This happened during severe gale force winds, though the weather was not considered extreme storm conditions [12]. The investigation concluded that the structural failure occurred in one brace, due to a fatigue failure initiation from a gross fabrication defect, which caused progressive failure of all the other braces.

The Japanese online Failure Knowledge Database published a detailed assessment of the failure [13]. The brace that failed from the gross fabrication defect was identified as D6, which contained a hydrophone installed in a circular hole that was cut in the brace, and welded with double fillet welds. Cracks about 70 mm long, and related to lamellar tearing in the heat affected zone contained traces of paint, therefore they were introduced during fabrication. No weld defects were found at any other location, which indicates that the design rules were followed for all other welds. In addition to lamellar tearing, incomplete penetration, slag

6.4. Studija slučaja: Petrobas P-36 - Brazil 2001

Nacionalna uprava za aeronautiku i kosmos (NASA) u SAD-u ima publikaciju pod nazivom Studije slučajeva neuspeha gde se detaljno analiziraju određena tema ili situacija. U pregledu naftne platforme Petrobas P-36, koja je potonula 20. marta 2001. godine, objavljene u oktobru 2008. godine, identifikovani su direktni i indirektni uzroci ove katastrofe [11].

Neposredni uzrok je bio pripisan curenju isparljivih tečnosti koje su zapalile zatvoreni rezervoar za odvodnjavanje u slučaju nužde, a koji je izazvao tragičan sled događaja, što je dovelo do 11 smrtnih slučajeva i potpunog gubitka naftne opreme. Indirektni, osnovni uzroci bili su kombinacija korporativnog fokusa na smanjenje troškova zbog sigurnosti, lošeg projekta pojedinačnih delova u vezi sa sigurnosnim kontekstom sistema, loma komponenata bez dovoljnih rezervnih kopija i nedostatka obuke i komunikacije.

Rukovodioci kompanije Petrobas su implementirali "agresivno i inovativno" smanjenje troškova prilikom projektovanja i proizvodnje proizvodnih pogona P-36, dok su "naglasili da je projekat uspešno odbacio utvrđene ograničavajuće i negativne uticaje inženjeringa na bazi propisa, preterane zahteve kvaliteta i zastarele koncepte inspekcije i kontrolu klijenata i da je "uklanjanje ovih nepotrebnih mesta za zatezanje" dalo superiorne finansijske performanse" [11]. Njihove izjave nisu uključivale koje su analize sproveli da bi se utvrdilo kako ove inovacije utiču na sigurnost, pokazujući kako korporativna kultura može biti faktor koji doprinosi kritičnim otkazima.

6.5. Studija slučaja: Alexander L Kielland – Norway 1980

Platforma Alekander L Kielland je prevrnula 27. marta 1980. godine, što je dovelo do 123 smrtna slučaja. Ovo se dogodilo usled snažnih sila vetra, mada se vreme nije smatralo ekstremnim olujnim uslovima [12]. Istraga je pokazala da se lom konstrukcije pojavio u jednom nosaču, zbog otkaza usled zamora iniciranog velikim defektom pri izradi, što je uzrokovalo progresivno otkazivanje svih ostalih nosača.

Japanska onlajn baza podataka o otkazima objavila je detaljnu procenu [13]. Nosač koji se polomio iz velikog defekta pri izradi, identifikovan je kao D6, u kome je bio hidrofon instaliran u kružnom otvoru koji je isečen u nosaču i zavaren dvostrukim ugaonim zavarenim spojem. Prsline dugačke oko 70 mm, vezane su za lamelarni lom u zoni uticaja toplotom, sadrže tragove boje, što znači da su nastale tokom izrade. Na bilo kojoj drugoj lokaciji nisu pronađeni defekti, što ukazuje na to da su

inclusions and root cracks were introduced by welding on flame-cut edges that were ground back to clean metal before welding. The materials used for the hydrophone also did not meet the requirements for the application.
In this instance, organisational and human factors were identified that contributed to the catastrophic failure [12]. These can also be classified with respect to engineering and inspection deficiencies:
The engineering deficiencies were:
• A fatigue design check was not carried out;
• The relevant Codes did not require damage tolerance assessment; and
• Damage stability rules did not assess the consequences of the loss of a column on the whole structure.
The following inspection deficiencies occurred during fabrication, inspection and maintenance inspection:
• Poor welding practice resulted in fabrication defects;
• Inadequate inspection did not identify the critical welding defect; and
• Maintenance inspections did not include the bracing containing the hydrophone weld.

7. Avoiding engineering disasters
Welding is a key industrial process used to create practical solutions in answering perceived needs, and is used extensively all over the world.
Welding affects the engineered properties of materials and can result in catastrophic failure, as highlighted by the various case studies. It therefore requires careful control and management to achieve the design requirements, and it is recommended that the application requirements should influence the design requirements of welds.
But incorporating weld quality management alone is not sufficient, and therefore ethical conduct during all aspects of projects should also be part of the process.
7.1. Interactive approach incorporating quality management
While the common concept model, as referenced in Figure 1 has provided a basic framework to deliver projects from design to inspection, a more interactive model, illustrated in Figure 4 [5], is proposed to address the influence of product or application requirements, therefore quality, over the whole process, especially with respect to welds.
Each element is not isolated and should therefore not be implemented in a linear fashion, but rather in such a way that the application of the product influences the aspects of design, materials, fabrication and inspection. The application will also therefore determine the level of quality

pravila za projektovanje ispoštovana za sve druge zavarene spojeve. Pored lamelarnog loma, nepotpuno uvarivanje, uključci troske i prsline u korenu nastale su zavarivanjem na ivicama posle gasnog rezanja, koje su bile izbrušene do čistog metala pre zavarivanja. Materijali koji se koriste za hidrofon takođe nisu ispunili uslove primene.
U ovom slučaju identifikovani su organizacioni i ljudski faktori koji su doprineli katastrofalnom otkazu [12]. One se takođe mogu klasifikovati u pogledu inženjerskih i inspekcijskih nedostataka:
Inženjerski nedostaci bili su:
• nije sprovedena provera projekta na zamor;
• relevantni propisi nisu zahtevali ocenu tolerancije oštećenja; i
• pravila o stabilnosti oštećenja nisu procenile posledice gubitka stuba na celu konstrukciju.
Tokom izrade, inspekcije i održavanja inspekcije došlo je do sljedećih nedostataka u pogledu inspekcije:
• loša praksa zavarivanja dovela je do defekata u izradi;
• neadekvatna inspekcija nije identifikovala kritični defekt u zavarenom spoju; i
• inspekcije pri održavanju nisu uključivale veze koje sadrže zavareni spoj hidrofona.
7. Izbegavanje inženjerskih katastrofa
Zavarivanje je ključni industrijski proces koji se koristi za stvaranje praktičnih rešenja u odgovoru na zapažene potrebe, a široko se koristi u celom svetu.
Zavarivanje utiče na osobine materijala i može dovesti do katastrofalnih otkaza, što je istaknuto u različitim studijama slučaja. Zbog toga se zahteva pažljiva kontrola i menadžment kako bi se ispunili zahtevi za projektovanje, a preporučuje se da zahtevi primene utiču na projektne zahteve zavarenog spoja.
Međutim, uvođenje/primena menadžmenta kvalitetom zavarivanja nije dovoljno, te stoga etičko ponašanje u svim aspektima projekata takođe treba da bude deo procesa.
7.1. Interaktivni pristup koji uključuje menadžment kvalitetom
Iako je uobičajeni model koncepta, kao što je prikazano na slici 1, obezbedio osnovni okvir za realizaciju projekata od projektovanja do inspekcije, predložen je interaktivniji model, ilustrovan na slici 4 [5], kako bi se naglasio uticaj zahteva proizvoda ili primene, stoga kvalitet, tokom čitavog procesa, naročito u odnosu na zavarene spojeve.
Ni jedan element nije izolovan, zbog čega ovaj model ne treba sprovoditi u jednom pravcu, već radije na takav način da primena proizvoda utiče na aspekte projekta, materijala, izrade i inspekcije. Tako će primena takođe utvrditi nivo potrebnog

management needed. This means that the required level of performance and therefore quality is incorporated during design, materials selection, fabrication and inspection, as shown in Figure **5**. Guidance to select the required weld quality management level can be found in the ISO 3834 series of documents: Quality management for fusion welding of metallic materials: Part 1: Criteria for the selection of the appropriate level of quality requirements [16].

menadžmenta kvalitetom. To znači da je potreban nivo performansi i samim tim i kvalitet uključen tokom projekta, odabira materijala, izrade i pregleda, kao što je prikazano na slici 5. Smernice za odabir potrebnog nivoa menadžmenta kvalitetom zavarivača mogu se naći u seriji dokumenata ISO 3834: Menadžment kvalitetom kod zavarivanja topljenjem metalnih materijala: Deo 1: Kriterijumi za izbor odgovarajućeg nivoa zahteva kvaliteta [16].

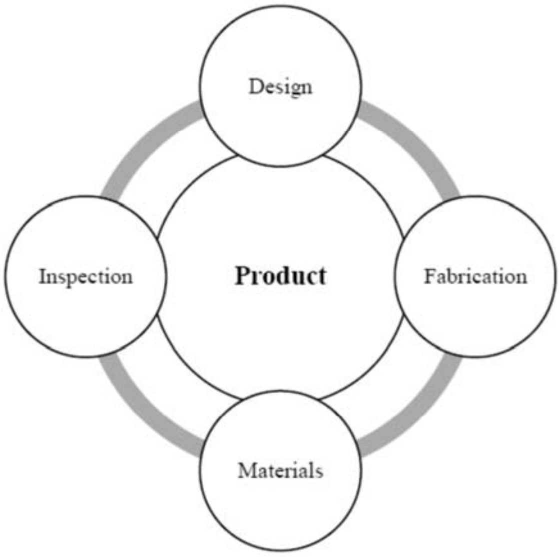

Figure 4: *Interactive model [5]*
Slika 4: *Interaktivni model [5]*

Figure 5: *Quality management as part of the engineering process*
Figure 5: *Menadžment kvalitetom kao deo inženjering procesa*

7.2. Supporting professional conduct and ethics

Engineering and inspection ethics have been influenced many times by corporate culture and management decisions, resulting in catastrophic failures [11, 12, 13, 15 and 17]. Anethical culture can be implemented the same way that a safety culture begins with management and employee engagement, and it can form the core of quality,

7.2. Podrška profesionalnom ponašanju i etici

Inženjerska i inspekcijska etika su mnogostruko uticale na korporativnu kulturu i odluke menadžmenta, što je dovelo do katastrofalnih lomova [11, 12, 13, 15 i 17]. Neetička kultura se može primeniti na isti način na koji bezbednosna kultura počinje sa menadžmentom i angažovanjem zaposlenih, a može da formira jezgro kvaliteta, engineering and inspection, as illustrated in Figure 6.

inženjeringa i inspekcije, kao što je ilustrovano na slici 6.

Figure 6: *Ethics forming the core of quality, engineering and inspection.*
Slika 6: *Etika koja čini jezgro kvaliteta, inženjeringa i inspekcije*

Recommendations from NASA [17] incorporating the lessons learnt from the Apollo, Challenger and Columbia disasters, addressed corporate culture issues in the following way:

- Reporting Culture: reporting concerns without fear of reprisal;
- Just Culture: treating each other fairly;
- Flexible Culture: changing and adapting to meet new demands;
- Learning Culture: learning from successes and failures; and
- Engaged Culture: everyone doing their part.

Preporuke NASA-a [17] koje uključuju lekcije naučene iz katastrofa Apollo, Challenger i Columbia, rešavala su pitanja korporativne kulture na sledeći način:

- Kultura izveštavanja: prijavljivanje zabrinutosti bez straha od odmazde;
- Prava kultura: pošteno uzajamno tretiranje;
- Fleksibilna kultura: menjanje i prilagođavanje kako bi se zadovoljili novi zahtevi;
- Kultura učenja: učenje iz uspeha i neuspeha; i
- Angažovana kultura: svi učestvuju.

8. Conclusion

Engineering failure can be caused by human factors, design flaws, materials and welding issues or extreme conditions, but also as a combination of these. Underlying these aspects are issues around quality and ethics. Therefore, implementing an organisation culture of ethical behaviour, with an integrated process in design, fabrication and inspection supported by the appropriate quality management requirements, can prevent catastrophic failures, so that quality equals safety.

8.Zaključak

Neuspeh u inženjeringu mogu prouzrokovati ljudski faktori, nedostaci projekta, materijali i problemi zavarivanja ili ekstremni uslovi, ali i kombinacija svega ovoga. Osnova ovih aspekata su pitanja kvaliteta i etike. Zbog toga, sprovođenje organizacione kulture etičkog ponašanja, sa integrisanim procesom projektovanja, izrade i inspekcije uz podršku odgovarajućih zahteva za menadžment kvalitetom, može sprečiti katastrofalne propuste, tako da je kvalitet jednak sigurnosti.

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