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Dear colleagues,

Marian Ritter
Director Exhibitions

You are holding in your hand the fourth and last issue of the Pipeline Technology Journal filled with papers of the 15th Pipeline Technology Conference. We were able to publish more than 40 papers of ptc 2020 in these special issues. EITEP as the publisher of ptj and organizer of ptc would like to take this opportunity to thank all the authors who took the time and effort to contribute their papers.

If you read the pipeline industry news these days, you will read a lot about decarbonization but also about the topic of hydrogen which is picking up speed again after long time - also thanks to massive economic policy measures. New projects are started, inspections, repairs and life-cycle-extension are topics. Also, Nord Stream 2 remains exciting. All this sounds like a time of much activity in the industry. But travel restrictions and home offices have become part of everyday life in many companies and that limits their actions.

To solve the current lack of face-to-face networking, our platform of Virtual Pipeline Summits serves as a solution. More than 100 participants from pipeline operators already registered for its second edition on 7 October 2020 which will be on the topic of "Leak Detection and Third-Party Impact Prevention". Registration is still open and free of charge.

Many people are aware that these online-only events cannot be the permanent solution: The online presentation of companies and technologies is feasible on online platforms, but they lack intuitive networking.

That is why EITEP is launching the 16th Pipeline Technology Conference in Berlin from 15 – 18 March 2021 and invites you to this high-quality B2B event. ptc Berlin offers all the elements you are accustomed to from ptc: Conference, exhibition, networking, social program. To maintain the high level of internationality, we are offering all those who cannot attend the ptc Berlin in person the ptc Remote, a platform with which they can get involved in the live event.

I look forward to meeting you all again next year in Berlin at Europe's leading pipeline conference and exhibition.

And now I wish you a good time reading the current issue of the Pipeline Technology Journal. Stay healthy.

Sincerely yours

Marian Ritter, Director Exhibitions, EITEP Institute

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PIPELINE PEOPLE: MARCELINO GUEDES GOMES, PETROBRAS

Marcelino Guedes Gomez joined PETROBRAS in 1987 where he worked in several different positions before he became Executive Manager, responsible for developing and applying solutions for illegal tapping in pipelines at PETROBRAS from 2015 to 2020. He studied Mechanical Engineering at the Pontifical Catholic University of Rio de Janeiro (PUC-RJ), gained his Masters in Civil Engineer from the Federal University of Rio de Janeiro (COPPE/UFRJ) and his MBA in strategic Knowledge Management from PUC Paraná. He attended a specialization course in terminals and pipeline engineering from PETROBRAS. Marcelino is member of the Pipeline Commission of the Brazilian Oil and Gas Institute (IBP), former Chair of the Pipeline System Division of the American Society of Mechanical Engineering (ASME), an elected ASME fellow, former President of ABENDI - Brazilian Society for Non-Destructive Testing and Inspection, Member of Industry Advisory Board – IAB/ASME, former President of the Pipeline Technology Center – Brazil (CTDUT) and member of the Pipeline Technology Conference (ptc) Advisory Committee. After almost 34 years dedicated exclusively to PETROBRAS, he has recently retired and founded PIPELINEBRAZIL.

Read more at:
https://www.pipeline-journal.net/news/pipeline-people-marcelino-guedes-gomes-petrobras

Europe´s Gas Supply Network: Key projects for trenchless methods and Pipe Express®

Diana Rennkamp, Michael Lubberger > Herrenknecht AG

Abstract

For the gas supply in Europe, a reliable pipeline network has the highest priority. Besides the construction of the main supply pipelines such as TurkStream and TAP, the fast and safe installation of the regional country-specific distribution networks like Eugal and Zeelink play a key role.

Different points of view of all involved parties have to be considered when it comes to the planning of routes and the evaluation of potential installation technologies. Due to a rising public attention paid to environmental issues and landowners´ concerns, the impact of pipeline construction on the surroundings has to be reduced to a minimum. While a large proportion of cross-country pipeline installations are still executed by conventional open-trench methods, trenchless technologies are considered for sensitive crossings or pipeline landfalls. Pipe Express, as a semi-trenchless method, presents an alternative where open-cut methods would cause high efforts, reducing required right of way (ROW) by 70% with less impact on surroundings.

For the crossings of waterways or protected areas, trenchless solutions are usually considered. Along the TAP route for example, various Direct Pipe® and HDD crossings have been executed. The landfall in Southern Italy (Adriatic Sea) was designed as a pipe jacked casing tunnel, similar to the landfalls of Nord Stream 2 in Lubmin (Baltic Sea), Germany and the TurkStream connections in Anapa (Black Sea), Russia.

Proven in more than 130 crossings worldwide, the Direct Pipe® technology is now back in Germany, where the EUGAL pipeline route crosses the former River Oder region (northeast of Berlin) on a 600 m long section. This paper will present the latest trenchless and semi-trenchless pipeline installations along Europe´s major pipeline routes, including examples for the offshore-onshore connection of LNG terminals and gas fields.

1. INTRODUCTION

Today, one quarter of Europe´s energy demand is covered by natural gas. Although a considerable increase of renewable energies is driven forward within the European Union, the share of natural gas in the energy mix is expected to remain on the current level of about 500 bcm on a mid-term basis. As Europe´s own gas reserves have already been exhausted in the past and European production of natural gas will continue to decline, more than 70% of Europe´s gas already has to be imported. This share will still rise in the next decades. Thus, European countries will increasingly depend on gas imports in the future to assure production of heat and electricity for private households and energy for the industry.

In 2018, 89% of European gas imports were supplied via the existing pipeline routes. Only a minor part was delivered as liquefied natural gas to the LNG terminals. The main suppliers are Russia, Norway and North African States. In the past, Russian gas was mainly delivered via the Ukraine and Belarus route to Europe. But with the Nord Stream Pipelines through the Baltic Sea, especially the controversial Nord Stream 2 Pipeline currently under construction and the recently inaugurated TurkStream pipeline, the importance of former transit routes will be weakened. Additional sources, like the further development of LNG Terminals and the connection to the Shah Deniz Gas fields in Aserbaijan via the TAP pipeline, are supposed to provide supply reliability and flexibility to the European gas market. In order to create a reliable and sustainable network for the upcoming decades, existing pipelines have to be expanded and new pipeline capacities have to be built. Innovative construction methods are needed to fulfill the project requirements, to match the time schedule and to comply with environmental regulations and concerns.

Open-trench construction methods are commonly the most efficient and fastest pipeline construction methods for cross-country pipeline installations. But in most pipeline projects it is not possible to trench the whole pipeline route. Hence, it will be necessary to cross existing surface and sub-surface obstacles such as roads, railways, underground installations and waterways along the pipeline route.

Different trenchless pipeline construction methods are available to cross obstacles on the route in a safe, effective and environmentally acceptable manner. Innovative technical concepts enable these technologies to be used also in the construction of outfall structures and pipeline landfalls. Whereas in conventional HDD or Direct Pipe® the product pipeline is directly installed, methods from the tunnelling industry provide pipe jacked or segmentally lined casing tunnels in which the pipeline is inserted in a second step. In order to assure Europe´s gas supply for the next decades, the whole range of technologies can be applied along the main pipeline routes and national distribution networks.

2. PIPELINES FOR EUROPE´S GAS SUPPLY

Hereafter, some case studies will show the involvement of different pipeline installation technologies along some of the main pipeline routes to Europe, the national distribution networks and interconnectors.

2.1. NORD STREAM 2, BALTIC SEA

The controversial Nord Stream 2 pipelines (2 x 48"), which is currently under construction, will link Europe to the worldwide largest gas reserves in Russia. The new pipeline runs mostly parallel to the existing Nord Stream 1 Pipelines (2 x 48"), which were inaugurated in 2011. Each pipeline system is able to supply a transport volume of 55 bcm/year. The 1,224 km twin pipeline system through the Baltic Sea stretches from Vyborg, Russia to Lubmin near Greifswald, Germany.

2.1.1. LANDFALLS CONSTRUCTION WITH PIPE JACKING, GERMANY

The landfall section in Lubmin, Germany, was designed as two pipe jacking tunnels to host the 48" pipelines. Two Herrenknecht AVN2000 with an outer diameter of 2475 mm have been used to install the parallel sections of 715 m length each. Trenchless technology was the preferred method to underpass the onshore road, supply lines and railway tracks and the sensitive coastal forest, dune and beach with maximum safety.

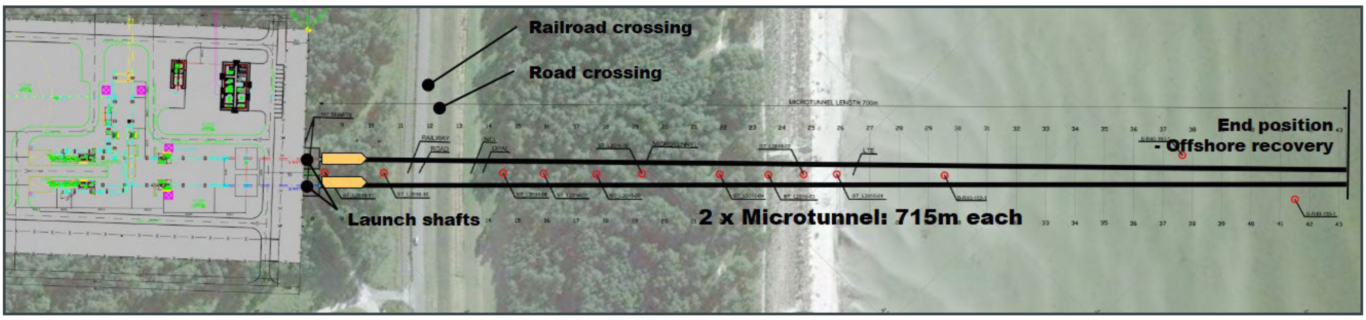

Figure 1. Overview of the two microtunnels for the Nord Stream 2 landfalls in Lubmin, Germany

Figure 2. View in the microtunnel (left) and AVN2000 machine after recovery from the seabed (right) [Source: Strabag]

Both tunnels led through sand, marl and boulders and were completed in May 2018. A special challenge was the subsequent recovery of the machine on the seabed. Therefore, the tunnelling machine was equipped with a special recovery module for remote-controlled disconnection of machine from tunnel. This procedure presents the only offshore activity necessary on the 715 m long offshore-onshore connection. The special heavyweight ballasted pipestring was then pulled into the tunnel from offshore to onshore with a winching system capable of approx. 4000 kN of pullforce.

2.2. EUGAL PIPELINE

The new EUGAL pipeline is of considerable importance for the European Union on the way to diversify transport routes and to assure gas supply for all member countries in the future. Designed as a 56" pipeline, the EUGAL runs 95% parallel to the OPAL pipeline and uses the existing corridor to minimize impact on the environment. The 485 km long EUGAL pipeline, of which 330km as twin pipeline, will connect Nord Stream 2 in Lubmin with the German-Czech border. The annual capacity of 55 bcm will mainly be used to feed the Czech Net4Gas network. Only 20% of the gas will go to Western Europe.

Along the 14 lots of the EUGAL route, numerous rivers (15), roads (140) and railway tracks (25) have to be crossed. The following references present some examples using respective trenchless technologies like HDD, Direct Pipe® and Microtunnelling. The EUGAL construction works started in September 2018 and are planned to be completed by the end of 2020.

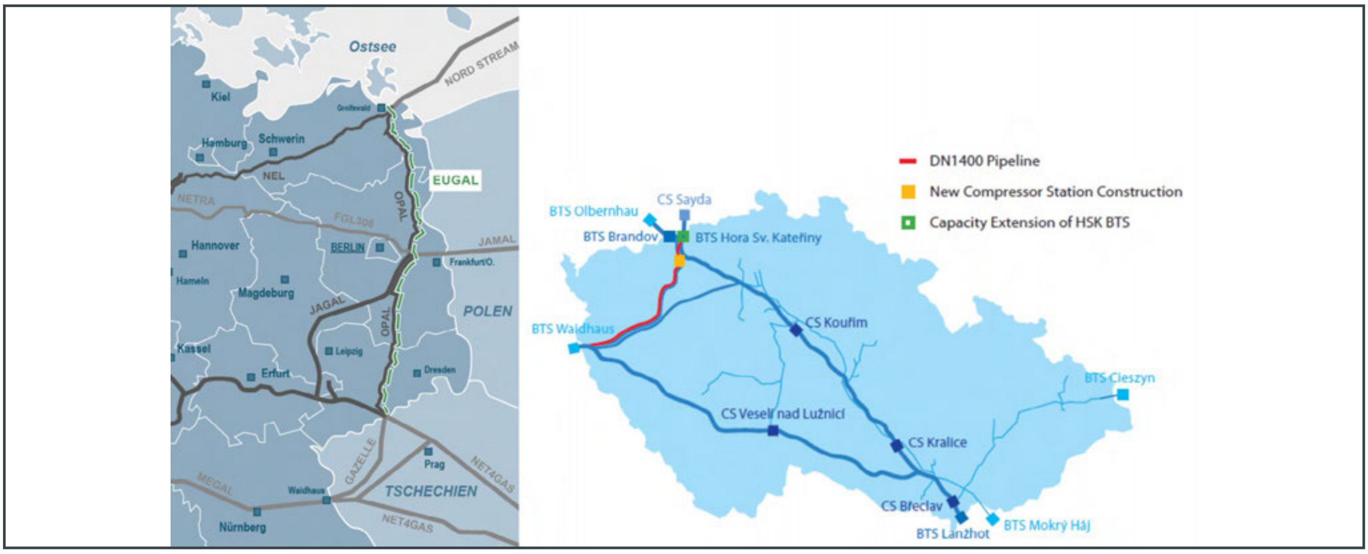

Figure 2. View in the microtunnel (left) and AVN2000 machine after recovery from the seabed (right) [Source: Strabag]

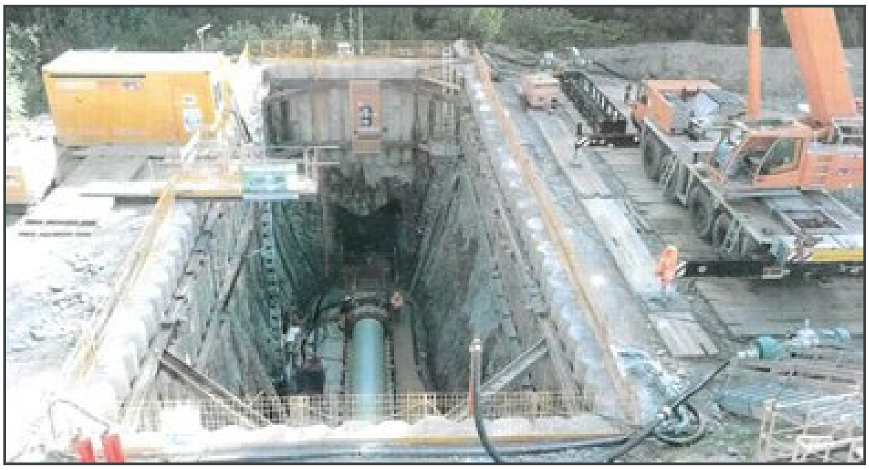

Figure 4. View into 14m deep launch shaft with 18 m long 56" pipeline section [Source: Petzold Rohrleitungsbau]

2.2.1. SHORT RIVER, RAILWAY & ROAD CROSSINGS WITH STEEL PIPE JACKING, GERMANY

On the Southern section of EUGAL (Lot 13 & 14), close to the Czech border, the German contractor Rohrleitungsbau Petzold was using a Microtunnelling Pipe Jacking Machine AVN1200TB to cross five of the smaller obstacles, e.g. Highway BAB A4, the Bobritzsch River and a street with an important sewer line. Individual drilling lengths between 18 m and 96 m had to be overcome.

The 18m long 56" gas pipe sections with a wall thickness of 22. mm were directly pushed behind the AVN machine into the borehole with the aid of a long jacking frame. This procedure necessitates , that after each installed pipe a new pipe has to be lowered into the shaft, welded, tested and coated. Because the alignment of these kind of trenchless crossings are normally designed as short as possible, the launch shaft has to be nearly as deep as the traversed obstacle. In comparison to the Direct Pipe® technology, where the Pipe Thruster is setup near the surface and generally longer pipe sections are continuously installed, this type of steel product pipe jacking method requires the jacking frame to be setup in a very long launch shaft with lengths of minimum 20m.

On the five described crossings for the Eugal shafts of up to 14m depth had to be built. Due to the project conditions, two of the crossings had to be executed following an upward inclination of 13-14%. A hydraulic pipe brake was mounted in the launch shaft to hold the installed pipeline in its position during the transition of the jacking frame position and during the coupling and welding of the next pipe section. A further challenge on four of the crossings was the compressive strength of the Erzgebirge (Ore Mountains) rock with up to 266 MPa paired with very high abrasivity. However, the extremely strong main bearing and main drive of the AVN-machine in combination with the assembled rock cutting head were able to achieve acceptable performances even under these demanding circumstances. Drilling speeds of around 30-70 mm/min in the softer rock (around 30 MPa) and of approx. 10-40 mm/min in the very strong rocks (160-266 MPa) could be reached. With regard to the experiences gained from the construction of the OPAL pipeline ten years ago, a considerable wear of the cutting tools was expected. Therefore, the machine was regularly equipped with new cutting tools.

2.3. TURKSTREAM PIPELINE

In January 2020, the TurkStream pipeline has been officially opened. The twin pipeline systems leads from Anapa Russia to the Northwest Turkish coast, on a length of 930 km through the Black Sea. On the Russian side, the available infrastructure from the formerly planned Southstream pipeline was used, e.g. the landfall microtunnels in Anapa described below. With an estimated gas transport volume of 31 bcm, the TurkStream pipeline will partly replace the existing Blue Stream pipeline which will mainly supply gas to the Eastern part of Turkey in future. Istanbul and surroundings will be served by one of the two new pipelines. The other pipeline string will lead throughout Bulgaria and Serbia to Hungary and will deliver gas to South East and Central Europe. The Bulgarian pipeline section is currently under construction. The Interconnector through Serbia was completed in 2019.

Figure 5. TurkStream pipeline route [Source: Gazprom]

2.3.1. LANDFALL WITH PIPE JACKING, RUSSIA

Due to the complex ground conditions in a highly seismic region, the two landfalls of the formerly planned South Stream pipeline were designed as microtunnels to host the 32" steel gas pipelines. Due to the coastal topography of the Caucasus Mountains near Anapa, the launch shaft was constructed at an altitude of 80 m. Thus, tunnelling out to the Black Sea involved underpassing the cliff face with a very steep declination descent of 11.5 % to reach the target point in 30 m below sea level. Two remote-controlled AVN 2000 Slurry machines for pipe jacking were used to install the 1,440 m and 1,470m long tunnel sections. According to the maximum overburden of 163 m and the altitude difference of 80 m, the slurry system and pumps were designed for 8 bar internal pressure. Furthermore, the machine was equipped with stronger steel plates to withstand potential rock squeezing.

Due to the very long drive length, a total of 10 intermediate jacking stations were installed to provide sufficient jacking force. A volume-controlled bentonite lubrication system was successfully used to keep jacking forces as low as possible. Through a highly variable and partially fractured rock mass with anticipated groundwater, the average performance rate was 15-21 m/day. Both landfall microtunnels were completed in April 2017.

2.3.2. DANUBE RIVER CROSSING, INTERCONNECTOR SERBIA

A gas pipeline system of 402 km length and a diameter of 48" will connect Bulgaria and Hungary throughout the Serbian territory. On its way, the Transmission Gas Pipeline (Interconnector) had to cross several obstacles. About 10 of the larger crossings between 500 and 1000 m length were undertaken using the HDD technology. In Kovin, 50 km east of Belgrad, the Danube River had to be crossed on a length of 1,409 m. As HDD appeared too risky to apply in the highly permeable soil, the crossing was originallydesigned as a microtunnel. Due to the tight time schedule, the installation of the concrete pipe casing and the subsequent insertion of the steel pipeline was considered as a too time-consuming procedure making two single steps necessary. Finally, Direct Pipe® was chosen as the preferred installation method, as excavation and installation of the prefabricated steel pipeline are taking place in one single step, providing safe excavation and continuous support of tunnel face and borehole at the same time.

With two Pipe Thrusters of 750 ton pushforce each, all 4 pipeline sections were successfully installed to complete this 1,409 m long river crossing. Whereas the Direct Pipe® distance world record has been set in New Zealand in 2018 at 1,930 m length, the Danube crossing in Serbia presents the current European distance record.

The drive through mixed formations of sand, silt and gravel was completed end of November 2019 with a best daily performance of 120.8 m (24h) and a maximum weekly progress of 407.5 m.

2.4. THE SOUTHERN GAS CORRIDOR

The Southern Gas Corridor project aims to increase and diversify Europe´s energy supply by bringing gas from the Caspian Sea to European countries. The gas is produced offshore in the Azerbaijanian Shah Deniz natural gas-condensate fields and will be transported to Europe via three main pipeline systems: South Caucasus Pipeline (SCP) and its expansion (SCPX) through Azerbaijan and Georgia to Turkey, the construction of the Trans-Anatolian Natural Gas Pipeline (TANAP) through Turkey to Greece and the Trans Adriatic Pipeline (TAP) through Greece, Albania and the Adriatic Sea to Southern Italy.

2.4.1. AUGER BORING, SOUTH CAUCASUS PIPELINE EXPANSION (SCP – SCPX)

The expansion of the South Caucasus Pipeline is part of the Shah Deniz Full Field Development project. This expansion involves the laying of a new pipeline across Azerbaijan and the construction of two new compressor stations in Georgia. This will triple the gas volumes exported through the pipeline to over 20 bcm per year.

Figure 6. Direct Pipe® jobsite installation at Danube River (left) and two Pipe Thruster HK750PT (right) [Source: Herrenknecht AG]


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INNOVATION FOR PROTECTIVE PIPE INSTALLATION
With E-Power Pipe®, Herrenknecht has developed a new method to quickly and securely install small-diameter cable protection pipes underground with drive lengths of over 1,000 meters. The trenchless technology can be precisely controlled and used with only small overburdens, thus offering a ground-conserving alternative to the conventional open-cut method for high-voltage grid expansion.
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Figure 7. Overview of the Southern Corridor gas pipeline projects [Source: Herrenknecht AG]

Guided Auger Boring is very often used for short pipeline crossings such as under traffic routes. As part of the SCPX, solely in Azerbaijan more than 100 of such underground crossings with maximum lengths of up to 95 m have been executed with steel pipe jacking. The project involved crossing roads and highways, rail lines, the BTC pipeline (Baku-Tibilisi-Ceyhan pipeline) and the WREP pipeline (Western Route Export pipeline), irrigation channels and local oil and gas pipelines. The overburden was between 1.5 m and 6 m, the launch shafts had depths of 3 m to 7.5 m and the pipeline diameter was 48" without coating. The geology mainly consisted of medium- dense to dense clay with partly high groundwater levels, which, however, was unproblematic owing to the cohesive soil. The soil was displaceable with SPT values < 35 – 40.

The contractor TTS (Tunel Tikinti Servis) from Baku was responsible for the steel pipe jacking and in consultation with Herrenknecht/Bohrtec decided to use two long frame machines of the types BM 800 L and BM 800 LS, which only differ in their torque. Due to the tolerances of max. 1% specified by the client and because of the displaceable soil, Guided Pilot Pipe Jacking with intermediate reaming was chosen as the method variant. Since jacking the product pipes directly with the augers inside was not permitted, initially temporary steel pipes with a diameter of 1245 mm were jacked. The intermediate reaming diameter was 609 mm. After completion of this steel pipe bore, the temporary steel pipes were pushed out using the product pipes. Both machines had a max. jacking force of 300 t. The concrete abutments in the launch shafts were sized in accordance with this maximum jacking force. The steel pipe length of 12 m meant that welding and testing times could be minimized, achieving an average drilling speed of about 12 m/hour.

2.4.2. MICROTUNNELLING, TRANS-ANATOLIAN PIPELINE (TANAP)

Before the 1,850 km long TANAP pipeline throughout Turkey could start operation in June 2018, trenchless technologies had been used on several crossings along the pipeline route. In 2017, two Herrenknecht Slurry microtunnelling machines were in operation on two locations in Turkey to cross roads and other obstacles underground. In Ardahan, close to the Georgian border, two short road crossings of 25 m length each were executed in rock conditions. An AVN1400 with extension kit for jacking ID 1600 reinforced concrete pipes of 3 m length installed both tunneled casings. In Sivas, a similar AVN equipment was used to jack steel pipes of 12m length. A total of four road crossings was executed in mixed ground of clay and rock with drive lengths from 80 to 100 m.

Figure 8. Extension with intermediate step [Source: Bohrtec GmbH]

Figure 9. Installation of final product pipe

Figure 10. AVN 1400 road crossing jobsite in Sivas, Turkey [Source: Herrenknecht AG]

2.4.3. DIRECT PIPE®, TRANS-ADRIATIC PIPELINE (TAP)

The TAP pipeline is connected to the TANAP pipeline in Tipoi, close to the Turkish- Greek border. Along the further TAP route through Greece and Albania various HDD crossings have been undertaken. For two 48" crossings of the Aliakmonas River in Kastoria, Northwestern Greece, close to the Albanian border, HDD was also considered in the early design stage of the project. But geotechnical investigation indicated a high content of gravel exceeding 70% share on some of the sections with layers of hard rock and loam. Due to these conditions, Direct Pipe® turned out to be the better suited technology. A special cutting wheel of the AVN 1000 Direct Pipe® machine was designed to face the geological conditions on the project. On the first crossing of 540 m length, one single pipeline section was installed. The pipeline for the second crossing of 612 m length was divided into 3 sections.

On the Albanian part of the TAP pipeline, several AVN microtunnelling machines for pipe jacking were used to install pipeline casings under roads and rivers. In Corovoda, Albania, an AVN 1800 has tunneled a challenging mountainous section consisting of colluvium and rock with a compressive strength of up to 120 MPa. Two drives with a total length of 1,160 m were completed in 2018.
Similar to the Nord Stream 2 landfall in Lubmin (Germany) and the TurkStream landfall in Anapa (Russia) pipe jacking has also been the solution for the landfall of the TAP pipeline in Southern Italy. An AVND2000 with extension kit for pipe OD 3000 has been in operation in 2019 to install the 1.5 km long casing tunnel from the launch shaft onshore to the target point on the seabed.

Figure 11.Overview on Direct Pipe® jobsite in Greece (left) and Pipe Thruster HK500PT installed in launch shaft [Source: Chrobok PPI]

3. PIPE EXPRESS®: ALTERNATIVE TO OPEN-CUT

As described above, trenchless technologies are required for the crossing of roads, railway lines and rivers along Europe´s main pipeline routes. Nevertheless, the major part of pipeline installation consists of cross-country sections. These are mainly executed by open-trench methods. In order to meet environmental requirements and property rights and to improve public acceptance, the semi-trenchless Pipe Express method was developed. The Pipe Express concept presents an economic alternative to open-cut construction, especially in soil with a high groundwater level. As the equipment needs only 30 % of the corridor compared to open-cut, it demonstrates its benefits under restricted space conditions or where environmental protection is the major concern. Additionally, the operation of Pipe Express requires less staff and machinery.

Similar to Direct Pipe®, the pipeline is pushed together with the machine by the Pipe Thruster from the shallow launch pit towards the target point. The major difference is the transport of the excavated soil, as Pipe Express does not use a slurry circuit. After full-face excavation a screw transports the soil through the machine to the vertical trenching unit (30 to 40 cm width) to the surface. Up to 2,000 m long pipelines with a diameter of 760 – 1,500 mm (30" - 60") can be laid quickly and cost-efficiently. Pipe Express® can also be used for the construction of pipeline landfalls. Therefore, the machine is pushed together with the pipeline into the water and following the seabed level.
The application of Pipe Express is currently discussed on several projects being planned in Europe. The advantage of reduced space requirements seems to be the decisive argument and has to be considered already in the early planning stage of the pipeline route.

4. OUTLOOK

Looking towards 2030, the gas demand in Europe appears to be likely stable. Predictions in the current climate change discussions are anyway not really sharp and hard to be foreseen. Gas will definitely play a key role in Europe's energy transition. Like Germany, many other countries are obliged to the Paris climate agreement and need to act rather sooner than later. Gas-fired power plants can buffer coal and nuclear phase-outs in the short and medium-term. Furthermore, gas will be required to provide flexibility for the variable renewable electricity (wind, solar, hydropower) due its ability for storage at large scale and availability across all seasons. Pipeline systems for gas in general can be used for the following types of gases as Biogas, Biomethane, Hydrogen and Power-to-methane. Especially the Green Hydrogen seems to have a bright future. Within this technology, hydrogen is produced through electrolysis of water using renewable electricity. It is very likely that the existing gas grid will be extended towards the new demands of Hydrogen pipeline and facilities.

Not only the Nord Stream 2 discussions between the EU, Germany, Russia and the United States show the importance of a required mix of different gas supplying countries. European supplying countries mainly rely on pipeline systems for transportation, whereas countries like the U.S. or Qatar deliver their gas as LNG to the European coastline. Especially LNG terminals require landfalls of the incoming gas.

Figure 12. Working principle of Pipe Express® [Source: Herrenknecht AG]

Figure 13. Corridor needed for open-trench [Source: Herrenknecht AG]

Figure 14. Narrow corridor for Pipe Express® [Source: Herrenknecht AG]

Due to the new large import pipelines to Europe some countries are forced to build up their own supply chain. Prime example is Poland with its plans for LNG terminals and the new Baltic Pipe project which supplies gas from Norway via Denmark to the Polish coast.

The planning and permit process for new pipelines in Europe requires implementation of the latest technologies in building open-trench and trenchless pipeline systems. New focal aspects in the construction industry will be the environmental footprint and impact of the machinery during the phase of construction. Technologies which promise to be eco-friendly, fast and cost-effective will be used and will replace old techniques very quickly.

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Key cyber-security controls for reliable pipeline operation

Jean-Francois Wirrmann > SIEMENS Energy

Abstract

Our corporate public IT domains (like siemens.com) are constantly under cyber-attacks since they are connected to the public internet network. In a 2015 survey of 314 organizations operating Industrial Control Systems (ICS) around the world, 34 percent of respondents indicated that their systems were breached more than twice in the last 12 months. 44% of organizations were unable to identify the source of the attack.

Due to low cost Information and Communication Technologies (ICT) and rapid Return Of Investment (ROI), the digitalization use cases implementations in the energy sector will on one side increase, but on the other augment the cyber-attack surface, and consequently the potential risk level, due to the introduction of new Industrial Internet of Things (IIOT) components and edge/cloud AI/ML/5G technologies.

Oil and Gas midstream transmission pipelines will be no exception: they are critical infrastructure and rely upon their core Safety Instrumented Systems (SIS) for ultimate business continuity and safety.

Targeting the Operation Technology (OT) environment of energy companies with malware (like Stuxnet Iran, Power Grid Ukraine, Triton Saudi Arabia) represents the bleeding edge of nation-state hacking activities. To inflict even more destructive damages on opponent's critical industry some advanced hacker organizations aim to disable safety functions on SIS systems, causing potential harm to people's health, the environment as well as on valuable assets.

This paper presents Siemens view on key cybersecurity defensive mechanisms based on the pipeline control & communications systems defence-in-depth approach, focusing on SIS protection measures, sequence of event (SOE) clock synchronization, multi-factor authentication, early-warning cyber intrusion detection and ransomware recovery. They all contribute to reliable pipeline operation.

This is a shortened version of the paper. To read the full paper please visit the ptc Paper Database

1. INTRODUCTION

The energy industry has become the second most prone to cyber-attacks with nearly three-quarters of U.S. oil & gas companies experiencing at least one cyber incident.

A cyber-attack against the ICS (Industrial Control System) of oil and gas pipelines can result in severe consequences to human and environmental safety in the form of ruptures, explosions, fires, releases, and spills. In addition, disruption of service and deliverability can be devastating for key infrastructure end users such as power plants, airports or national defence.

It is not a matter of if it will fail, but when it will fail. It is just a matter of time when some pipeline OT (Operational Technology) area/equipment will be compromised.

There is a consensus that 100% OT/ICS security cannot be provided, but the security level shall be set such as the remaining risk to be at an acceptable level determined by each OT asset owner.

2. MAJOR PUBLIC ICS INCIDENTS

ICS systems in critical infrastructure sector like pipelines can be a target for attackers, mainly organised as nation-state sponsored groups qualified as APT (Advanced persistent Threat). Here is an overview of the yet "publicly known" ICS cybersecurity related incidents. For more information refer to [1][2][3][4][5][6][7][8][9][10][11]

3. SERVICES AND APPLICATIONS ALONG A PIPELINE

IT security has been devoted for decades to the protection of information focusing typically on confidentiality first, then protecting integrity and lastly availability (called CIA triad). OT is founded on the reliability and safety of people and environment, which can be due to loss or reduction of OT Availability or OT Integrity. Selecting the proper type of security protection resources depends on the asset OT or IT business value, that could harm its Availability, Integrity or Confidentiality. To operate a terrestrial or subsea pipeline many control/operational systems are required. They are distributed in two information systems domains, the Corporate Information System (CIS) and the Industrial Information System (IIS). CIS belongs to the generic IT domain and IIS to the generic OT domain.

Figure 1 depicts the two domains with their typical services. The IIS domain shows the control & communications applications along a pipeline and how they could be grouped depending on their function and the pipeline operation entity who will use it.

Each IIS group gets mapped to a security risk level / profile SPi (i=1..3) and if necessary be noted with a redundancy requirement (R):

- SP3 : Safety Critical Elements - SIS and Safety Critical Element with Programmable Electronic (SCE-PE) shall be classified SP3. (Highest Risk level)
- SP2 : Control Systems - All other systems shall be classified SP2. SP2 generally encompasses all SII systems essential to the production (e.g. PCS, Third party process Packages) (Medium Risk level)
- SP1 : Monitoring Systems - Monitoring systems which are not classified as SCE-PE, which are independent and have no communications with other SII systems with different security profile (although may have hardwired interfaces). Lower Risk Level

ICS Focused Malware	ICS Disruptive Events	Disruptive/Destructive Malware
• STUXNET • HAVEX • BLACKENERGY2 • CRASHOVERRIDE • TRISIS	• 2005-2010 (?): STUXNET • 2014: German Steel Mill Event • 2015: Ukraine BLACKENERGY3 • 2016: Ukraine CRASHOVERRIDE • 2017: Saudi Arabia TRISIS	• STUXNET • CRASHOVERRIDE • TRISIS

Table 1: Major Public ICS Incidents

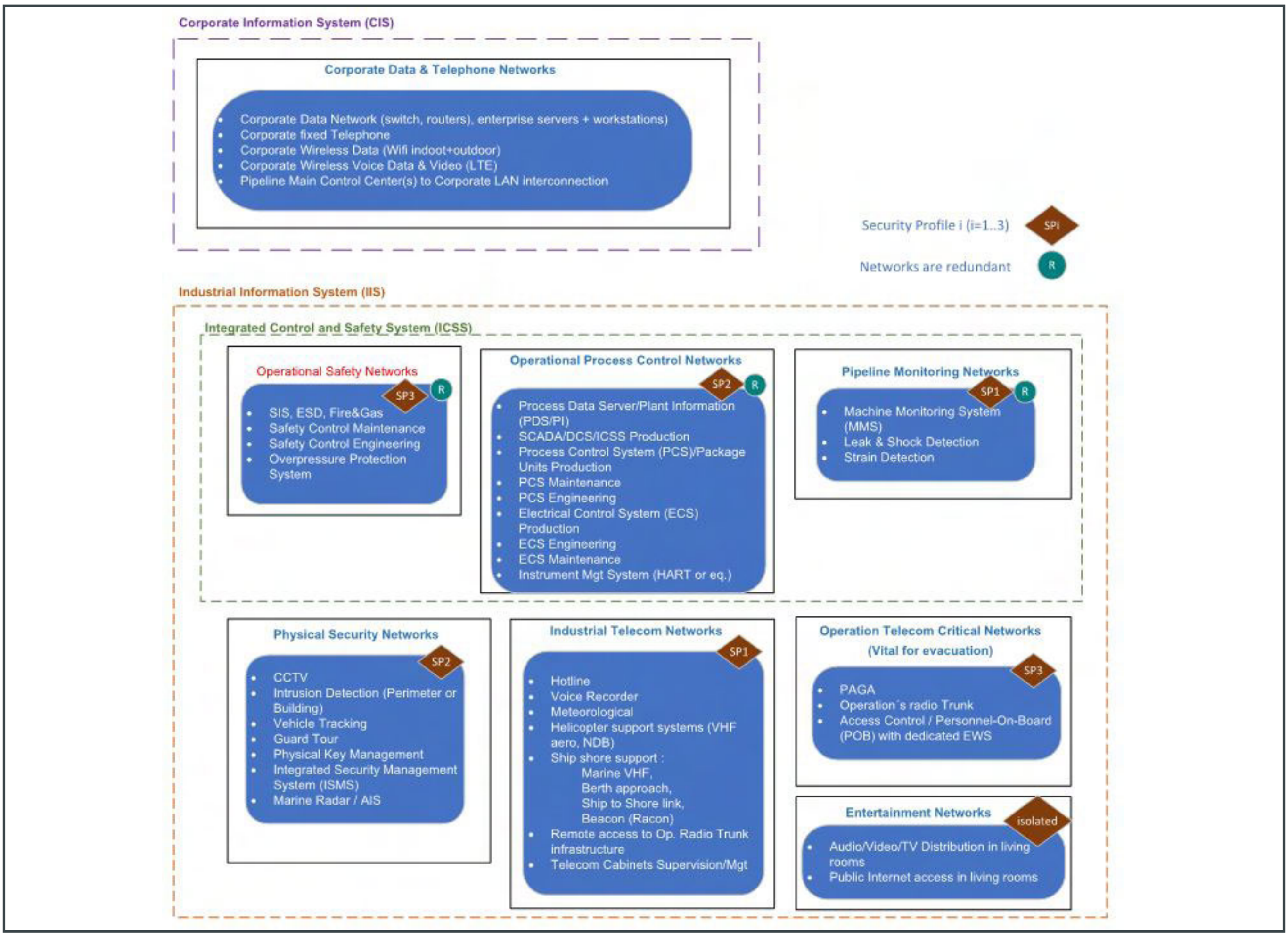

Figure 1: Oil & Gas pipeline applications overview

4. OBJECTIVES AND DIFFICULTIES OF AN ICS ATTACK

ICS attacks methodological steps have been described by Michael J. Assante and Robert M. Lee from the SANS Institute in their paper "The Industrial Control System Cyber Kill Chain" [12]. The authors state: "Although there are various ways to attack an ICS environment, the most common methods to achieve functional impact fall into three categories: loss, denial and manipulation. They include a loss of view, denial of view, manipulation of view, denial of control, loss of control, manipulation of control, activation of safety, denial of safety, manipulation of safety and manipulation of sensors and instruments".

In ICS the manipulation of sensors or the process could lead to the failure of safety systems designed of protect human life, lead to people injury and create a denial-of-service / unavailability one or more pipeline stations. Usually all stations of a pipeline are equipped with the same Instruments/SIS/PCS/SCADA equipment running identical software versions. Even if critical pipeline control functions are duplicated for avoiding hardware single failure the ICS attacker could apply his exploit to both instances without additional effort.

5. POTENTIAL ATTACK VECTORS FOR INDUSTRIAL FACILITIES

There are only a handful of vectors/pathways that can be used to launch a cyber-attack. The obvious ones are wired or wireless communication links. These can be high-bandwidth network (LAN or WAN) connections or simple point-to-point 'serial' links with another system/device. These can also be temporary links such as using a dial-in/out modem and phone line to temporary links such as using a dial-in/out modem and phone line to connect to another system/device (or the Internet itself.). Sometimes you have pathways that you don't realize: a cell phone with a "hot spot" provides a path to the Internet for a laptop equipped with Wi-Fi capabilities. Wireless connectivity comes in many forms today: laptop PCs with integral Wi-Fi and Bluetooth adapters. USB adapters that add Bluetooth or Wi-Fi capabilities to any computer. Cell phones that support 'tethering'. A rogue AP attached to an internal network. Cyber-attacks can be launched locally if the attacker has physical access to the computer or system. Cyber-attacks can also be initiated using infected computer-readable media or by connecting an infected device to a computer/ system. Malware has been spread through network-connected shared peripherals such as a network printer or copy centre.

An obvious attack path for a system is any communication interface (wired and/or wireless) that connects that system to other systems or devices. But the path too often overlooked, or underestimated, is the oldest one: Sneakernet. That is the transfer of electronic information by physically moving media such as magnetic tape, floppy disks, optical discs, USB flash drives or external hard drives between computers, rather than transmitting it over a computer network

An attack vector that has come to the attention of cyber security professionals in the past few years is what is collectively known as the "supply chain" which is a general term for malicious activities in the design, construction or on-going support of your systems. If an attacker is completely rebuffed by your physical and cyber- security measures, and willing to invest in a longer-term attack strategy, then your vendors could be used to attack your critical systems.

Typical attack vectors along a pipeline linear multi-site network topology could be:

- inter-site fibre optic or radio tap-in,
- physical access to unmanned facilities like a Block Valve station:
  - Example 1 : access physically a Block Valve Station which can be monitored by CCTV IP cameras, insert in the middle, and then pivot to the SCADA domain
  - Example 2 : penetrate inside the automation room of the block valve station, connect to network ports to start reconnaissance.

6. UNDERSTANDING THE ADVERSARY´S ICS CYBER-ATTACK CAMPAIGN

The kill chain is a military concept to model the structure of an attack: identification of the target, deployment of forces towards the target, confirmation of the order of attack and, finally, destruction of the target. Lockheed Martin has transcribed this concept to information security called Cyber Kill Chain 7 (CKC7). It includes seven steps: Reconnaissance, Weaponization, Delivery, Exploitation, Installation, Command & Control and Actions on Objective [12].

At the end of year 2015, the SANS Institute describes the CKC7 model as not directly applicable to ICS cyber-attacks but is it useful as a foundation to understand the process. The SANS authors recommend a two-stage model. The first stage 1 consists in cyber espionage but the actual attack on an ICS is accomplished in stage 2. The challenge for the cyber adversary intending to attack an ICS with significant effect, is that they must become well versed in the process being automated and the engineering design of the ICS and safety system. Refer to [12] for details on the method.

The challenge for the cyber adversary intending to attack an ICS with significant effect, is that they must become well versed in the process being automated and the engineering design of the ICS and safety system. This is required to generate a predictable and controllable effect on the target industrial process. They also need to become familiar with the specific hardware and software technologies being used. All those additional steps require for the adversary more time and effort, offering an opportunity for the defenders.

This assumption would break down if the layered defence in depth protection for IT and OT domains would be violated, for example systems where the ICS has some form of remote access or internet connectivity independent of the organization's IT infrastructure or any rogue wireless device connected to ICS wireless networks. These are historically not generally as well protected as those that go through various other protective mechanisms when traversing via the IT network and internal firewalls. As an example, backup connections to remote SCADA sites have been known to have been exploited in the past. Wireless networks that are not well secured in industrial plants or pipelines locations may also be a potential attack vector in some cases.

7. IMPROVING VISIBILITY IN ICS NETWORKS

An up to date OT domain asset inventory and OT network architecture are preconditions for cyber protection and the key controls presented in chapter 8.

Since you cannot protect what you don´t know, a precondition prior elaborating a protection strategy is to create and update (after any change) a detailed inventory of all OT (and IT) assets. Asset inventory is defined as resources (hardware, software, documents, services, people, facilities, etc.)

That can be tedious but is an absolute must for protecting your business from cyber-attacks. All assets which do possess network capable communication interfaces (Eth, IP, wired or wireless) shall be listed since all these network interfaces could be basically attacked.

An OT asset inventory is comprised of:

- Asset information

Hardware components	CPU, communication modules, I/O modules, network devices, gateways, computers…
Software components	Firmware, OS, SCADA or DCS software components…
System information	Asset name, vendor, type (PLC, RTU, HMI, SCADA server, remote I/O), model, serial number, OS or firmware, domain or workgroup
Network information	IP addresses, Mac address, domain, protocols used, open ports, gateway,…
Asset state information	Running, stop, program, test, decommissioned)
Contextual information	Geographic, plant, and process location, CPE (Common Platform Enumeration [15]), and other contextual aspects relevant for mapping vulnerabilities)

- Network Topology
  The asset inventory should also contain the network topology to provide complete visibility of the OT environment, including communication relationships: Industrial and/or IT protocols used, peer connections, role in the communication (client/server, master/slave).

  The OT (and IT if not yet available) network topologies documents must be created and updated after any change. Since those are golden nuggets for attackers they shall be handle as "confidential" and usually stored within asset owner's IT corporate network with adequate access protection measures.

Only by addressing this primary visibility gap can organizations and defenders then move on to addressing the fundamental problems posed by intrusions and gain the required initiative to detect attacks "as they happen" – allowing for the possibility of mitigation and prevention –rather than responding to attackers "after they occur".

8. ICS PROTECTION MEASURES FOR PIPELINES

Selected pipeline control protection measures described in this paper are already part of Siemens Energy Industrial Applications Onshore solutions portfolio. Siemens Energy provides many OT cyber-security activities during greenfield or brownfield pipeline or onshore projects lifecycle. In greenfield projects the typical OT cybersecurity services are OT cybersecurity consultancy, OT cybersecurity responsibility, OT Risk assessment, OT Design review, OT architecture/technologies/vendor/product proposal, OT network consulting, OT ICS design, OT Security Documentation, OT Security Testing during FAT and SAT, OT Monitoring services, OT Vulnerability Management, OT Patch Management. Within brownfield project Siemens Energy offers additionally OT asset inventories, Risk assessment, and support for upgrades or migrations.

8.1 KP#1 – SEGMENT PIPELINE COMMUNICATION NETWORKS

Network segregation will delay APT attackers for reaching more "valuable" ICS asset to impact the Availability of the AIC security OT triad and more dangerously tamper the physical oil & gas process.

Particularly in the world of pipelines this protection measure is essential because the pipeline is intrinsically composed of very distributed stations and systems and some stations along the route are or can be unmanned (Block, Pump, Meter, Compress, Control).

If an OT application needs to communicate been pipeline stations (Block valve, Pump station, metering station, compressor station, main control,…) the inter-site OT/IT architecture shall ensure that inter-site communications of each OT application is segregated from the others. For example, any required SIS controller inter-site production communications/network shall be totally segregated from other networks.

Within a station the network design shall be guided by the defence in depth approach to that it is difficult or impossible to access from a network or physical security point of view critical OT physical process or safety control, electrical control or communications assets.

OT application groups are are mapped to three Security Profile Levels (SP1..3)

Data exchange between two SP2 networks should favour point to point data layer 2 links or serial data links (the link shall not be routable).

Systems defined as SP3 shall have their own dedicated Engineering Workstation (EWS). It shall not be possible to configure an SP3 system from any other system.

Systems defined as SP2 and SP3 may communicate together via a dedicated interface network using non-routable communication cards. The use of IT equipment (i.e. servers, routers, switches, standard firewalls) in place of communications cards is not permitted. Unused network communication ports should be disabled or locked.

SP2 systems which require communications to other SP2 systems over distinctive networks will communicate via a firewall.

Systems defined as SP1 shall not communicate with any other SII system with different security profile except via hardwired signals.

A pipeline control and communication network design require both intra-station and inter-station network segregation. In the IEC 62443-3-3 standard the grouping/network segmentation approach is similar but uses the concepts of zones and conduits. “Zones” are logical or physical assets that share common security requirements. The zones then communicate exclusively through secure “conduits”. A conduit is any pathway of communication that enters or exits a security zone.

Pipeline inter-site network segregation was implemented in the past using technologies like SDH or building in parallel several industrial gigabit switches infrastructures. Nowadays the utilities are adopting the MPLS-TP technology where centralised provisioning and management are key selection criteria.

8.2 KP#2 – AUGMENT PROTECTION FOR SAFETY INSTRUMENTED SYSTEMS (SIS)

As described in several press articles [13] the OT attack called Triton/Trisis on Oil & Gas Plant ESD systems analysis revealed that the APT attackers where inside the victim´s plant three years before they launched the actual attack. The intent of the attacker was to manipulate the integrity of the ESD controllers, but no catastrophic physical disaster occurred. The APT group goal was sabotage and physical system damage (like burner over-heating or over-pressure). Before targeting the SIS controllers, the attackers were first getting a remote access foothold on the SIS engineering workstations from which they were also able to communicate to the outside world through an IP routed internet access.

Therefore, SIS systems shall be segregated from anything else and located ”as deep as possible” in the defence-in-depth architecture. The typical discussion is about the interfacing of the SIS with the BPCS (Basic Process Control System) and with the “Control Center” functions. There are different SIS segregation architectures possible [14] :

- Air gapped: SIS is interfaced to BPCS by a discrete wiring only
- Interfaced SIS: SIS is interfaced to BPCS with a point to point communication. This point-to-point connection does not travel over the same network interface that is used for other communications.
- Integrated 2 zone: the SIS and BPCS are fully integrated and provide direct, real-time communication between the systems. Information from the SIS zone is communicated to the BPCS and higher -level systems for monitoring purposes. This information should be read-only flowing from the SIS zone out to other systems.
- Integrated 1 zone: The SIS and BPCS systems are integrated in one zone providing much greater communication between those systems and higher-level systems in the architecture. There is only a single HMI and engineering workstation.

The choice depends on overall risk analysis and ICS solution providers system capabilities.

Process control BPCS and SIS Logic Solver PLCs should support enhanced cybersecurity protection functions:

BPCS Protection function	Description
Access protection	Protection against unauthorized configuration changes through authorization levels
Know-how protection	Protection against access and modifications to industry sector specific automation algorithms by means of password protection
Copy protection	Protection against duplication of programs
CPU physical lock	Protection against unauthorized access by locking the front cover with a seal or a lock

SIS Logic solver Protection function	Description
Access to Safety program	Protection against unauthorized access by offline and online passwords
Access to Fail-Safe CPU	Protection against unauthorized access by F-CPU password AND physical key switch cabled as input to the PLC.

Recommended SIS access protection:

- To the Safety program (offline and online passwords, preferably stronger authentication using multi-factors)
- To the Fail-Safe CPU (F-CPU password and seeking for multi-factor auth)
- Dedicate a specific Engineering workstation for Safety Management. Custom data and program shall be classified as ”confidential“ and stored and accessed accordingly in asset owner´s corporate office environment with proper backups. Access to the workstation enforced through multi-factor authentication.
- If case of station ICSS/SIS/ESD or Pipeline Safety Control functions isolate it from any other data networks (point to point serial links or hard-wired are possible)
- Any tentative to access a SIS controller for trying to change its firmware, configuration data or process engineering data shall be detected, and security enforced by placing inline a dedicated Security Gateway connected on a dedicated network port of the SIS controller. This solution can also be applied for other controllers (PCS). Which user is authorized to access which controller for which purpose is then managed centrally by the security solution.

8.3 KP#3 – PREVENTIVE PROTECTION FROM RANSOMWARE WITH A REGULARLY TESTED BACKUP SOLUTION

Ransomware is the malicious software which is designed to deny access to a system or data by encrypting files until a ransomware payment is arranged by the victim. Ransomware attacks have become less frequent, but at the same time, they're becoming more and more targeted and sophisticated.

Just before finalizing this paper a new Ransomware called SNAKE [16] was discovered. It targets entire corporate networks and possesses a dreaded level of obfuscation. Enterprise targeting ransomware are used by threat actors that infiltrate a business network, gather administrator credentials, and then use post-exploitation tools to encrypt the files on all of the computers on the network.

Upon successful infection, the SNAKE ransomware deletes the machine's Microsoft Shadow Volume Copies before terminating various processes associated with SCADA systems, network management solutions, virtual machines and other tools. It then proceeds to encrypt the machine's files while skipping over important Windows folders and system files. Attackers leave an instruction file on the computer's desktop:

According to a report of Cybersecurity Ventures released in 2019 a business will fall victim to a ransomware attack every 14 seconds by 2019, and every 11 seconds by 2021. When a ransomware attack gets successful, it can be extremely damaging, over 100k up to millions of dollars in losses for the organization.

In case of a ransomware infection impacting all or only part of the operations, the goal is to restore the overall pipeline process control continuity as soon as possible. It is very essential to take a backup of the data so that in case if any attack happens that time you have not to lose your data.

Old ICS systems may not have accurate or complete (or any) backups. The OT plant(s) might have the media (tapes?) used to initially install and commission the system but they may never have made any subsequent backups. In some cases, the backup media may prove to be unreadable or corrupt. Some process plants may have updated their peripheral devices (e.g. going from reel-to-reel magnetic tape to cartridge tape) and never made a new backup.

To avoid business OT data loss or critical control systems unavailability, one key security control part of any business continuity plan is to have an OT backup strategy in place. Getting a good backup made may be the critical first step before anything else can be done to an automation system or device. An industry best practice is to enforce a working procedure that states that any change to any OT asset shall be backed up. The backup procedure shall specify for each type of asset the four W: when, what, who, where. In addition, it might not be enough just to back up the important data and documents. Entire machines may need to be backed up, if they are critical to the business. In case of pipeline process control, the critical assets will be for example:

- Compressor - Pump – (Fiscal) metering - Station DCS server image and online data ,
- Pipeline SCADA & Pipeline server image and data,
- Historian server image and data,
- DCS/SCADA engineering project(s) repositories (including Process Automation offline programs and automation engineering data)
- SIS/ESD Engineering program and data,
- SIS/ESD controllers.
- Microsoft Active Directories
- Databases (MS SQL server, Oracle,...)

After a ransomware attack, if clean images of the infected machines were readily available, the asset owner could have completely wiped the infected hardware and restored it to the last good version. And organizations don't have to store multiple complete copies of every system -- incremental backup systems save just the latest changes, making them very efficient.

OT backup and restoration capabilities are part of the overall Business Continuity Planning involving both IT and OT domains. Obtain asset owner senior management commitment, initiate OT and IT teams' collaboration to identify business risk, elaborate, test and enforce the continuity plan in the organization.

A disaster recovery system can be extremely costly to set up and maintain within the organization. It is therefore essential to properly define the requirements of the recovery system by assessing per business application criticality defined by the RTO and RPO criteria [17].

The company IT/OT business continuity plan in place with proper OT backup strategies and procedures will be applied and enforced by the workforce (intern, contractor), with proper onsite supervision. OT Backups (system images, virtual machines, data in databases or files) shall be tested regularly for proper restoration, off-site or during plant maintenance phases.

The downside of current OT backup solutions for DCS, SCADA, EWS or Historian computers is that they are too specific, provide no automated control and too complicated to be handled by OT operations. Introducing virtualized OT servers and workstations and OT NAS File Server components in the OT domain would allow to simplify OT backup and restoration operations in case of loss of individual or a complete OT site (disaster). By replicating OT Virtual Machines one can achieve low recovery time objectives (RTOs). For workloads with less strict RTO requirements, ne can setup backup copy jobs to achieve the 3-2-1 rule. The 3-2-1 rule states you should have 3 copies of backups, on 2 different media, one of which should be offsite (remote site).

Pipeline control & communication systems with a security Profile SP2 and SP3 shall be designed for a disaster recovery. The determination of RTO & RPO values per SPx applications is the responsibility of the pipeline operating company / asset owner.

Introducing virtualization or private cloud technologies in chosen pipeline stations or OT control centres would not only help for better and easier cyber security controls but also contribute to several overall business benefits: uniform software computing architecture to support the different cloud types, edge computing and IIoT use cases, reduce foot print (space and energy).

8.4 KP#4 – SETUP ROBUST MULTI-FACTOR AUTHENTICATION (MFA) SCHEMA

Traditional pipeline control system SCADA/DCS/Historian/EWS computers access is only password protected. Two-Factor Authentication (or Multi-Factor-Authentication) adds a second method of identity verification to secure your accounts. First, the thing you know, your password, then something unique you own or have (keyfob, phone, smart card, fingerprint…). By combining your password with one of these factors, attackers can´t access your account even if they have your password. The on-premises solution (vs cloud solution) uses three main components:

- Authentication Manager
- Security Agents (installed on the computers or devices which shall be access protected). Challenges users for their security credentials and passing those credentials to an authentication manager.
- Authenticators / Tokens (Hardware keyfob, software mobile, software toolbar, on-demand SMS or email)

For cyber-security and availability reasons, to avoid internet bidirectional access from the industrial domain to a publicly connected OT employee mobile phone for 2FA authentication a typical solution is to operate with hardware based authenticators/tokens within the OT domain in a dedicated OT user/group role based directory (for example Microsoft Active Directory).

8.5 KP#5 – DETECT AS SOON AS POSSIBLE AN INTRUSION

Asset discovery and anomaly detection are key components of any Operational Technology (OT) cybersecurity strategy.

An important security control to defend against the attacker in the earliest step of the ICS Kill Chain Stage 1 is to detect, limit and block an attack (whether external/internal or un/intentional). It is therefore highly recommended to put detection capabilities in place.

8.5.1 MONITOR OT NETWORKS AND RESPOND TO INCIDENT

An attack on an Industrial Control System is always the result of an intrusion over several possible attacks paths and vectors, then a long period of maturation during which the cybercriminal will move in your network to find a security breach. He will then try to modify controller programs, change the set points and the parameters, and try to tamper with the process mainly external DCS/SCADA values as HMI and Field I/Os. To avoid the attacker to further progress in your networks as depicted in the ICS Kill Chain (refer to section 6), it is of utmost importance to know as soon as possible that some bad things are taken place in your network and have an incident response process and organization in place. The detection technologies can be signatures based, behavioural based or even now using Machine Learning algorithms.

Typical OT monitoring solutions consist of:

- Passive OT & IT network sensors:
- ICS protocol visibility and analysis by extracting metadata (Technology DPI – Depp Packet Inspection)
  - Asset discovery - visibility trough network scanning
  - Anomaly & Intrusion Detection
  - Used on brownfield ICS installations
  - ICS Endpoint (server, workstation, controller, industrial gateway, switch) intrusion sensor agent software:
- Adds detailed asset inventory data compared to passive detection
  - Preferred in greenfield projects since it usually requires additional software installation on ICS equipment.

8.5.2 TO SUPPORT FORENSICS THE SAME TIME SOURCE IS ESSENTIAL WITHIN OT AND IT DOMAINS

The reconstruction of events as part of computer forensics and incident response can involve events from only a single system, as well as events obtained from multiple, geographically separate sources, each with its own clock. An especially useful technique for event reconstruction is "time-lining". Here, discrete events that have a timestamp associated with them are ordered into a timeline. Timestamps can be obtained from file system metadata, system logs, or application data. Depending on the source of the events, this can provide a detailed sequence of the events that took place on a system (or multiple ones), allowing an investigator to reconstruct the sequence of events that took place. But OT time reference integrity is also very important for controlling the process as well (SCADA/DCS).

To fulfil OT time source availability and not breaking cyber-security network segregation a trade-off should be find where and how many OT time sources are required for controlling a pipeline. The principle is to implement at least two independent OT time references for each Security Profile SPi (i=1..3) within the OT (IIS) domain – usually located in main control centres – providing NTP (Network Time Protocol) master clock availability. NTP was not designed with security in mind.

8.5.3 COLLECT AND ANALYSE OT SECURITY EVENTS IN A UNIFIED SECURITY ORGANIZATION

An intrusion could start in any domain OT or IT. A unified IT/OT security strategy is the best way to manage asset owner´s entire digital risk, not only for a pipeline asset. An OT/ICS/IIoT security solution should provide asset & network visibility and integrate natively with asset owner companywide existing centralized security Operations Centre (SOC) to provide asset owner SOC with real-time information about OT assets, vulnerabilities and threats to give complete visibility.

To avoid OT and IT technical and organizational silos it is recommended to unify IT and OT security activities concerning security event analysis and incident response process by creating a unique Security Operations Centre (SOC) staffed with IT and OT security analysists/experts.

OT security events (issued by automation controller, industry gateways, OS, network device, application or passive anomaly sensor) will not be kept in the OT domain but replicated in the IT domain for storage in the unique IT/OT SOC companywide event database. This will enable event history, co-expertise in a unique security analysis team, and does not allow an attacker already in the OT domain to remove his tracks by deleting ICS security logs or events. Customizing and analysing security events generated by ICS equipment (controllers, PLCs) will usually require ICS vendor support.

9. CONCLUSION

Obviously, the end goal of a sophisticated external cyber-attack on an industrial control system could be devastating and potentially terrifying. It should be clear from the above that while many in industry are concerned that this may occur, it is nevertheless the domain of well-equipped and sophisticated adversaries.

All companies building or operating pipelines need to have a cyber-security risk-based strategy, an organization, measures in place and skilled staff. Obviously, this organization and these measures need to have enough funding to work smoothly. Besides individual programs, which are definitely important, a general OT/ICS policy/program should be in place which has to be approved by senior management and documented for later reference.

To avoid issues in the project execution of a greenfield pipeline project, we recommend defining OT cyber-security requirements and guidelines at the very early stage (before EPC contracting), so that the complete EPC/EIT supply chain involved in the execution can properly provision costs and efforts for related OT cyber-security activities. The remaining security level is always a balance between business impact and costs for implementing cyber-security controls and staff. It is established by risk assessment methodologies in basic and detailed design phases. The decision whether the level is acceptable or not for a given project relies within the asset owner.

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Friction Stir Welding of Steel for Pipeline Fabrication

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Abstract

Friction stir welding procedure development was initiated on steel grades S460 G2+M and S690QL1 in plate wall thicknesses of 10 and 15mm. To tackle the challenges of the high mechanical loads on the tool as well as its premature wear, a combination of preheating and optimized weld backing set-up was implemented. The inductive preheating allowed a 28% reduction in welding torque and a significant reduction of the tool wear, particularly during the critical initial plunge of the tool within the base material. A comparison of Mo-based and W-based tool was performed, allowing identifying the W-based tool as having a better combination of high temperature strength and wear resistance. Different backing arrangements and materials were investigated. Ceramic backing inlays were used to reduce the heat loss at the root area and maintain an acceptable stirring of this zone to achieve full penetration welds. The welds quality was assessed via metallurgical examination, bend tests and confirmed the possibility to perform sound full-penetration, one-sided welds. The contribution of the preheating to the process as well as the quality and mechanical properties of the welds will be presented here. Finally, the transfer of the process parameters to pipe welding were started and will be discussed here.

1. INTRODUCTION

The welding processes currently used for the fabrication of steel pipelines have essentially remained the same for the last 35 years. They all consist in multi-pass arc welding with various degrees of mechanisation and electrical waveform control. The strengths and weaknesses of such processes are now well understood and accounted for by the welding engineers. Among the weaknesses of multi-pass arc welding is the high propensity for weld defects, either between the weld and the adjacent substrate or between weld passes. The individual weld beads microstructure being closer to that of a casting, the achievement of the required mechanical properties depends strongly on the selection of the appropriate welding filler metal and the welding sequence. The weld geometry, at the cap and root, can also be detrimental to the fatigue resistance of the welded assembly. To further advance automation but also improve welds quality and mechanical properties, Friction Stir Welding (FSW) has been assessed as a potential disruptive technology. It also has the potential to allow high strength steel welding for deep-water applications. It is a solid-state one-shot process using a rotating tool to generate frictional heat at the interface between the parts to be welded. The substrate is softened and consolidated into a weld while contained between the tool and a backing support. The process is autogenous, and the weld mechanical properties are directly linked to the composition and metallurgy of the base material. Being a one-shot process, it allows a better control and a reduction of weld defects. It has also been suggested that the weld geometry offers better fatigue performances than arc welds.1

he economic viability of FSW depends on the context of application. The development costs as well as the machine and tool costs should be taken into consideration. For the welding of offshore pipelines, one of the key factors is productivity. With the welding operations performed on the lay vessel or on the quayside, any improvement in the number of weld performed per working shift can represent significant cost savings in terms of vessel or spoolbase working time.2 Considering typical Gas Metal Arc Welding (GMAW) cycle times from an offshore pipeline fabrication contractor's track records, with the welding operations performed in one work station (J-lay installation method), the FSW offers a welding cycle time advantage when the tool travel speed is above 2 mm/s on a 12" OD x 15.9mm thick pipe. At a travel speed of 4 mm/s the FSW is 30.3% faster than GMAW; this can represent a cost saving per weld in excess of 3000€. Additionally, better fatigue performances and the option to weld higher strength steels could allow more flexibility on pipeline and riser designs, thus generating additional cost savings to projects.

Already strong of a significant industrial application track record for aluminium welding, the process adaptation to steel presents several key challenges. Three of these are:

1) High mechanical loads on the tool
2) High tool wear and
3) Achieving consistent full penetration on one-sided welds performed on wall thicknesses representative of the offshore pipeline industry.

2 SCOPE AND OBJECTIVES

A combination of local pre-heating centered on the joint and back-wall insulation was implemented. The preheating parameters development was made after a detailed investigation of the through-thickness temperature distribution. The objective was to find the correct set of preheating parameters to sufficiently soften the base material through thickness to reduce the welding loads and tool wear while not excessively tempering the steel mechanical properties outside of the weld zone, in the heat affected zone (HAZ). The targeted maximum pre-heating temperature at 25mm away from the weld centerline was 600°C. A backing arrangement was necessary to counteract the welding down-force and retain some heat around the weld root. It has been established that good stirring of the root area is correlated to sufficient base material temperature in this zone, especially on thicker one-sided welds. Full penetration welds are in effect a requirement for pipeline girth welding.

3 EXPERIMENTAL PROCEDURE

Linear bead-on-plate (BOP) and butt welds of 200 - 250mm in length were produced to investigate the lifetimes of molybdenum- and tungsten-based FSW tools by producing fully consolidated, full penetration welds. The experimental setup is summarized in Table 1. Steel plates of grade S460 G2+M and S690 QL1 with a thickness of 10mm and 15mm have been investigated for the study. The respective chemical compositions are given in Table 2.

Table 1: Experimental setup for FSW-study on steels

FSW-tool	Welded steels	Welding speed [mm/min]	Welding depth [mm]
Mo-based	S460 G2+M	80 - 180	10
W-based	S460 G2+M, S690 QL1	120 - 360	10, 15

Table 1: Experimental setup for FSW-study on steels

Table 2: Chemical composition of the investigated steels (wt. - %)

Steel grade	C	Si	Mn	P	Cr	Ni	Cu	Nb	Ti
S460 G2+M	0,03	0,34	1,64	0,009	0,173	0,18	0,16	0,04	0,013
S690 QL1	0,15	0,29	1,45	0,012	0,329	0,03	0,02	0,02	0,013

Table 2: Chemical composition of the investigated steels (wt. - %)

The experiments on plate have been performed on a custom-built Stirtec‡ FSW-machine with a maximum downforce of 100 kN, a maximum spindle torque of 330 Nm and a maximum spindle speed of 3000 rpm. It is equipped with a cooling head and a 50kW inductive preheating system for a localized and controlled heat input in front of the FSW tool to preheat steel plates with a thickness up to 25 mm.

The used tools consist of a shoulder with a diameter of 25mm for 10mm and 32mm for 15mm thick plates and an unthreaded and tapered probe. Both tool materials can be easily redressed to their original design once excessive tool wear has been observed.

For a specific plate thickness and welding speed, the optimum temperature evolution during the preheating process on the top and bottom plate sides was determined since it has proved to markedly decrease the welding loads and tool wear during welding, respectively.3,4 This includes the stationary heating for the tool plunging phase and an instationary heating for the tool travel phase. Figure 1 shows the thermocouples setup used for both conditions.

Furthermore, different backing inlay materials were used for both mechanical support and thermal insulation to facilitate sound weld quality. To test these backing materials, a baseplate with exchangeable backing and insulating inlays was designed as shown in Figure 2. Different types of insulating and backing materials were tested including steels, ceramics and tungsten carbides.

To qualify the weld, metallographic analyses were carried out on transversally sectioned weldments, which were polished and etched in a 3% Nital solution. Moreover, the weld quality was evaluated by hardness tests, tensile tests, as well as face and root bend tests. The tool wear was evaluated by optical assessment and by X-ray fluorescence (XRF)-analyses on the weldments.

Before transferring the results from the plate to pipe and to weld higher grade materials at higher welding depths, an upgrade of the machine was performed. The machine was additionally mechanically reinforced, and a more powerful spindle was installed to enable a maximum torque of 600Nm and a radial force up to 40kN.

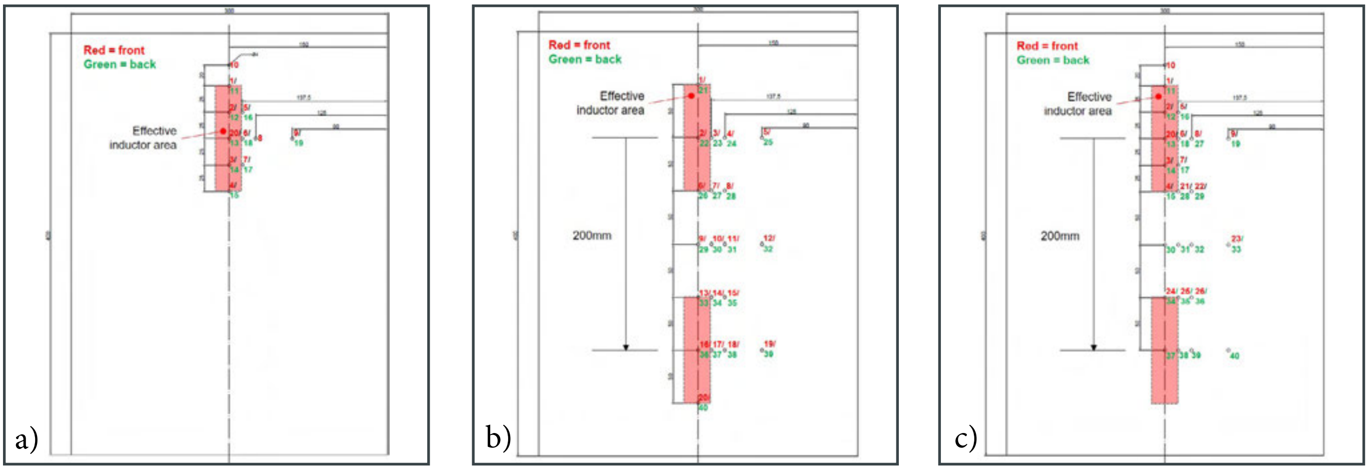


Figure 1: Thermocouple setup for a) 10 and 25mm thick stationary, b) 10mm and c) 25 mm thick instationary preheating tests

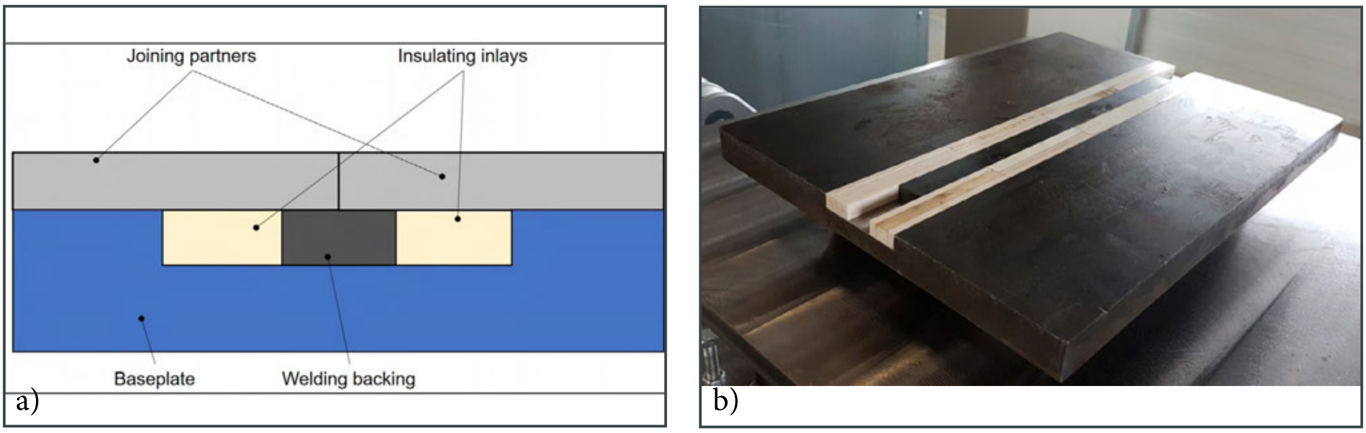


Figure 2: a) Schematic representation of the used backing setup, b) setup ready for use

To be able to weld pipes, an additional pipe rotating system was designed and manufactured as shown on Figure 3. The weldable pipe diameter ranges from 8-12 inch (NPS). The system is designed to fit two 600mm coupons for butt welding or 1400mm long single pipes for bead-on- pipe configuration. During the welding process the pipes are aligned, clamped and supported in the welding area by an internal backing system which fits the standard pipe tolerances. Exchangeable backing and insulating inlays can be placed in the backing system (comparable to the setup for the plate welds to simplify the parameters transfer). A new inductor was produced to fit the curved shape of the pipe and it can automatically be retracted from the surface.

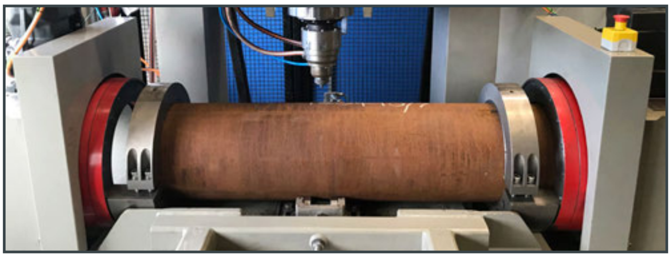
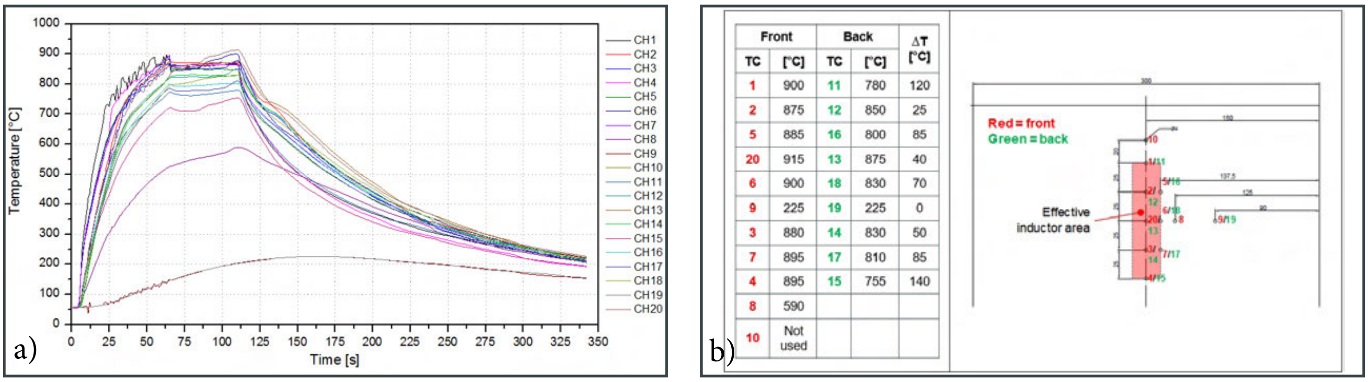


Figure 3: Weld set up for pipe welding

4 RESULTS

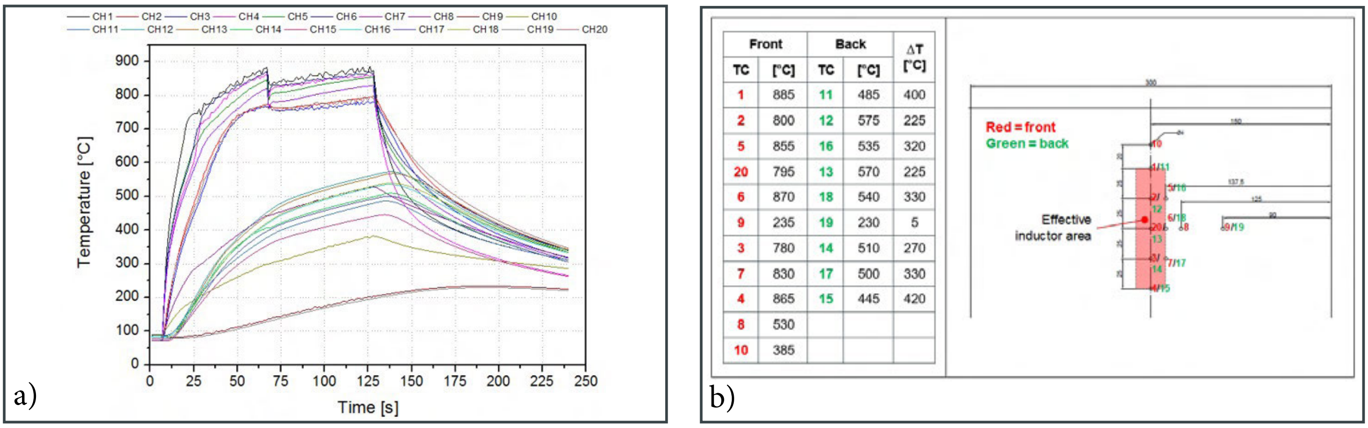
4.1 PREHEATING TESTS

The aim of the preheating tests was to determine the required parameters for through-thickness heating of the base material without both overheating the face side of the plate and impairing the mechanical properties next to the inductor and FSW tool shoulder region. The preheating parameters were chosen in order not to exceed 600°C in the future HAZ. The future stir zone of the weld was allowed to reach higher temperatures. This activity was part of the calibration process of the preheating system. Figure 4 shows the temperature curves during stationary preheating of a 10mm thick S460 G2+M plate. The maximum temperature difference between top and root side was 120-140°C along the front and back inductor edge and only 40°C in the center region. Compared to the 10 mm thick steel, the temperature gradient on the stationary 25mm S460 G2+M plate was significantly higher. The difference between top and root side was around 400°C at the inductor boundaries and 225 °C in the middle (Figure 5). A higher heat input to achieve higher temperatures on the root side caused an overheating of the base material next to the inductor.



Front		Back		ΔT
TC	[°C]	TC	[°C]	[°C]
1	900	11	780	120
2	875	12	850	25
5	885	16	800	85
20	915	13	875	40
6	900	18	830	70
9	225	19	225	0
3	880	14	830	50
7	895	17	810	85
4	895	15	755	140
8	590			
10	Not used			

Figure 4: a) Temperature curves and b) peak temperatures of the thermocouples for stationary preheating of a 10 mm thick S460 G2+M plate



Front		Back		ΔT
TC	[°C]	TC	[°C]	[°C]
1	885	11	485	400
2	800	12	575	225
5	855	16	535	320
20	795	13	570	225
6	870	18	540	330
9	235	19	230	5
3	780	14	510	270
7	830	17	500	330
4	865	15	445	420
8	530			
10	385			

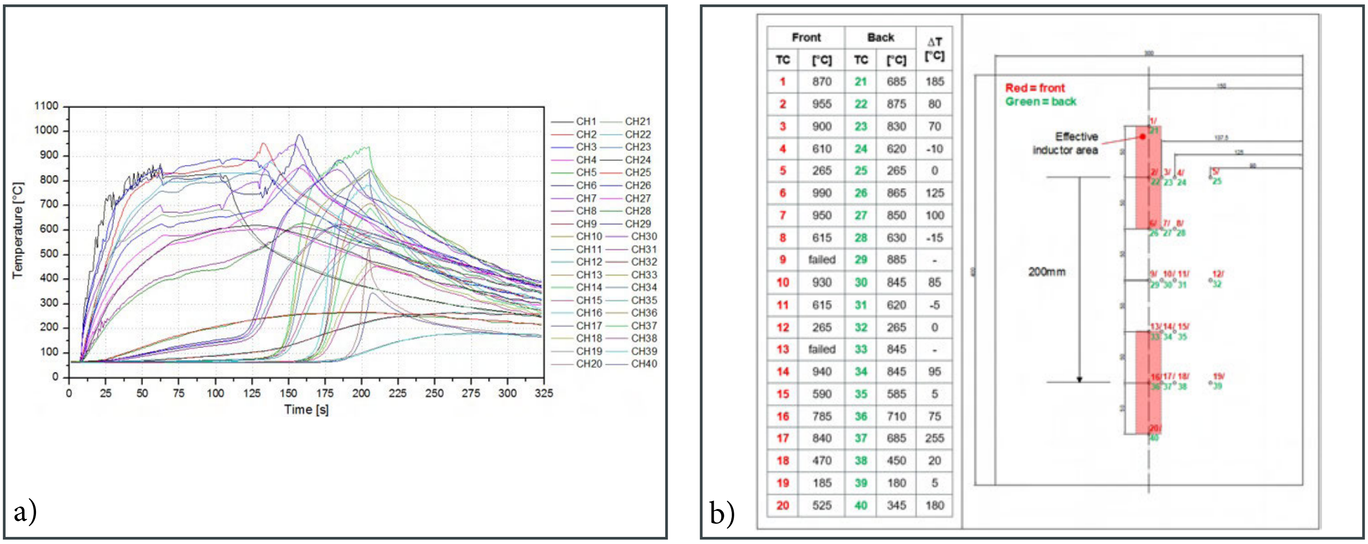
Figure 5: a) Temperature curves and b) peak temperatures of the thermocouples for stationary preheating of a 25 mm thick S460 G2+M plate

To determine the preheating parameters during welding, instationary preheating tests have been performed. For the 10mm tests, the temperature evolution during travelling showed a slight difference between top and root area (see Figure 6). In contrast, the root temperature on the 25mm plates (shown in Figure 7) was significantly lower compared to the 10mm plate tests.

4.2 INFLUENCE OF PREHEATING ON THE TOOL WEAR

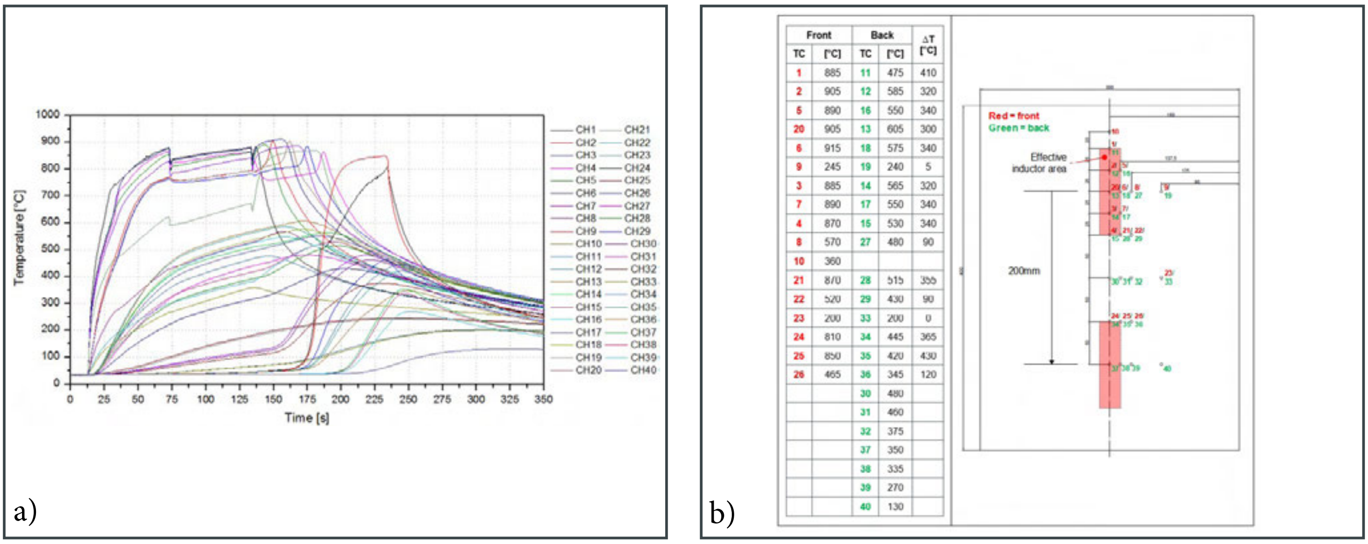
To determine the influence of a preheated base material, extensive series of weld tests with the Mo-based tool were carried out. Tests showed that most of the tool wear occurs during the plunging process. To minimize this effect, the steel plate was preheated in the plunging area before the rotating tool plunged into the base material.

To classify the wear, the length of the probe and the shoulder of the tool was measured after each plunge test. Especially the probe shows a considerable wear caused by the plunging process. Figure 8 shows a new and a used tool where this wear behavior is clearly visible. In Figure 9, the wear after 10 plunges, which means a contact time of the tool to the base material of around 250 second (~ 25 seconds per plunge) and 10 weld seams (each 250mm long), which means a contact time between tool and base material of 1500 s (~ 25 seconds per plunge and 125 s per weld seam) is shown. Comparing these results shows that 40 % of the length reduction of the probe happens during the plunging process which only represents 17 % of the process time (contact between tool and base material). Preheating reduced this wear significantly. Figure 9a shows the influence of preheating on the tool wear.



Front		Back		ΔT [°C]
TC	[°C]	TC	[°C]	
1	870	21	685	185
2	955	22	875	80
3	900	23	830	70
4	610	24	620	-10
5	265	25	265	0
6	990	26	865	125
7	950	27	850	100
8	615	28	630	-15
9	failed	29	885	-
10	930	30	845	85
11	615	31	620	-5
12	265	32	265	0
13	failed	33	845	-
14	940	34	845	95
15	590	35	585	5
16	785	36	710	75
17	840	37	685	255
18	470	38	450	20
19	185	39	180	5
20	525	40	345	180

Figure 6: a) Temperature curves and b) peak temperatures of the thermocouples for instationary preheating (travel speed of 120mm/min) of a 10 mm thick S460 G2+M plate



Front		Back		ΔT [°C]
TC	[°C]	TC	[°C]	
1	885	11	475	410
2	905	12	585	320
5	890	16	550	340
20	905	13	605	300
6	915	18	575	340
9	245	19	240	5
3	885	14	565	320
7	890	17	550	340
4	870	15	530	340
8	570	27	480	90
10	360			
21	870	28	515	355
22	520	29	430	90
23	200	33	200	0
24	810	34	445	365
25	850	35	420	430
26	465	36	345	120
		30	480	
		31	460	
		32	375	
		37	350	
		38	335	
		39	270	
		40	130	

Figure 7: a) Temperature curves and b) peak temperatures of the thermocouples for instationary preheating (travel speed of 120mm/min) of a 25 mm thick S460 G2+M plate

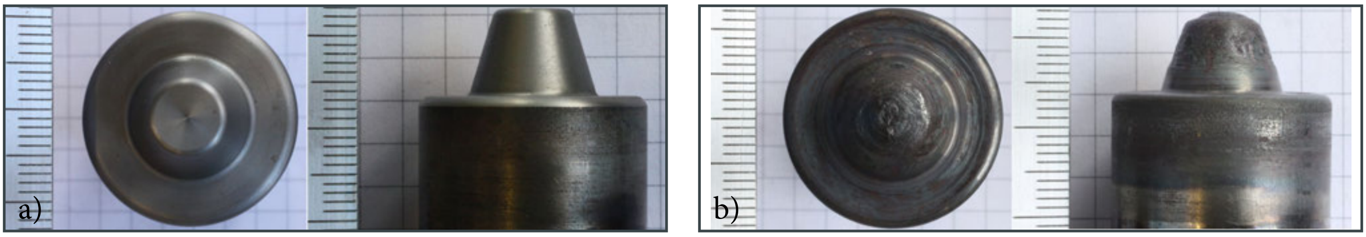


Figure 8: a) Unused Mo-based tool, b) Mo-based tool after 10 plunges without preheating

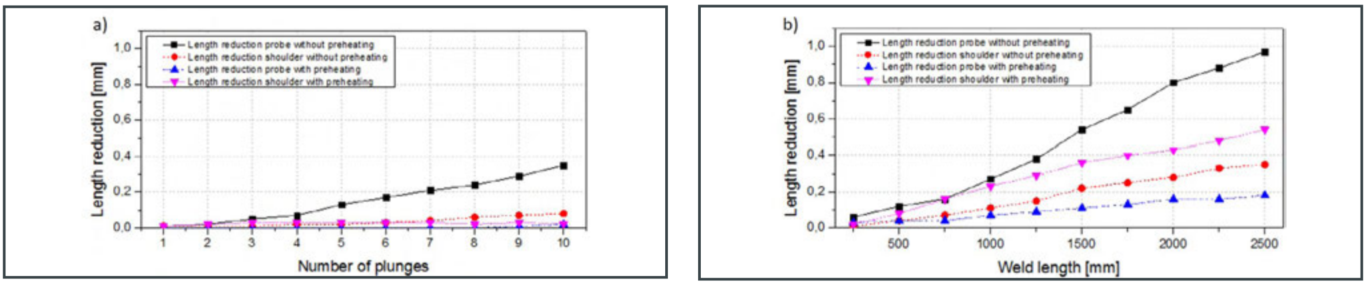


Figure 9: Length reduction during wear tests performed with a featureless Mo-based tool a) length reduction during plunging, b) length reduction during plunging and welding

During welding, the heat input of the preheating system was reduced to an amount that did not overheat the base material but still provides the beneficial effect on the tool wear. The wear was measured every 250mm for both set-ups. The results (shown in Figure 9b) showed a reduction in wear on the probe and a slight increase on the shoulder when preheating was applied. These tests were performed with the Mo-based tool. The W-based tool showed better wear behavior later during welding compared to the Mo-based tool.

4.3 INFLUENCE OF PREHEATING ON THE MACHINE LOADS

Preheating of the base material affects the welding process parameter and therefore the load on the welding machine. For thick section welding, this effect can be beneficial. To display the reduction potential, Table 3 shows two 10mm S460 G2+M steel grade weld tests performed with a Mo-based tool. One was performed with and the other one without preheating.

Table 3: Load reduction caused by preheating

	Without preheating	With preheating	Reduction [%]
Spindle torque [Nm]	310	230	28
Welding force [kN]	44	38	13,5

Table 3: Load reduction caused by preheating

4.4 S460 G2+M WELDING DEVELOPMENT

Starting with the Mo-based tool and bead-on-plate weld seams, a process development on 10mm thick S460 G2+M plates was performed. The process was then transferred to weld seams in butt configuration on two 150mm wide plates with square milled sides.

Figure 10 shows a cross section of one of the test welds. On the advancing side (AS) of the weld seam 5-7 mm under the cap side a dark region can be found. EDX analysis confirmed the assumption that this is a concentration of wear particles from the tool. Figure 11 shows the higher molybdenum content in the examined area.

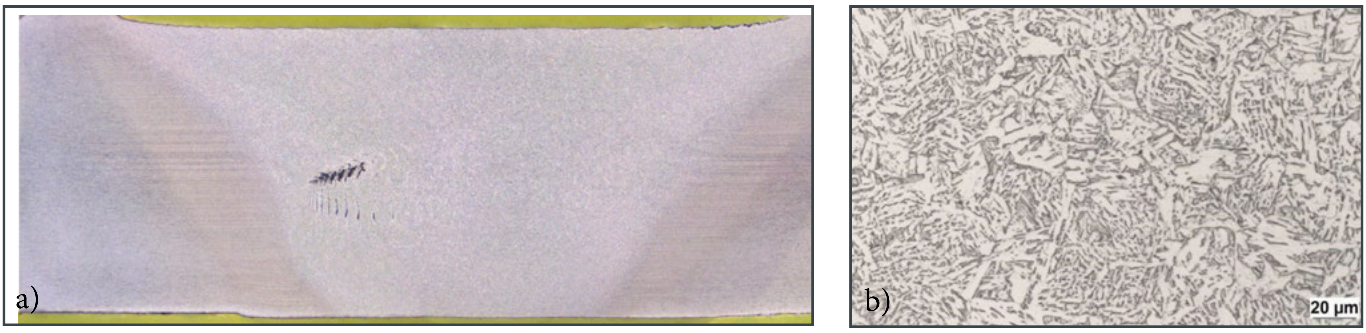


Figure 10: a) Cross section and b) microstructure of the weld zone of a 10mm S460 G2+M weld seam performed with a Mo-based tool.

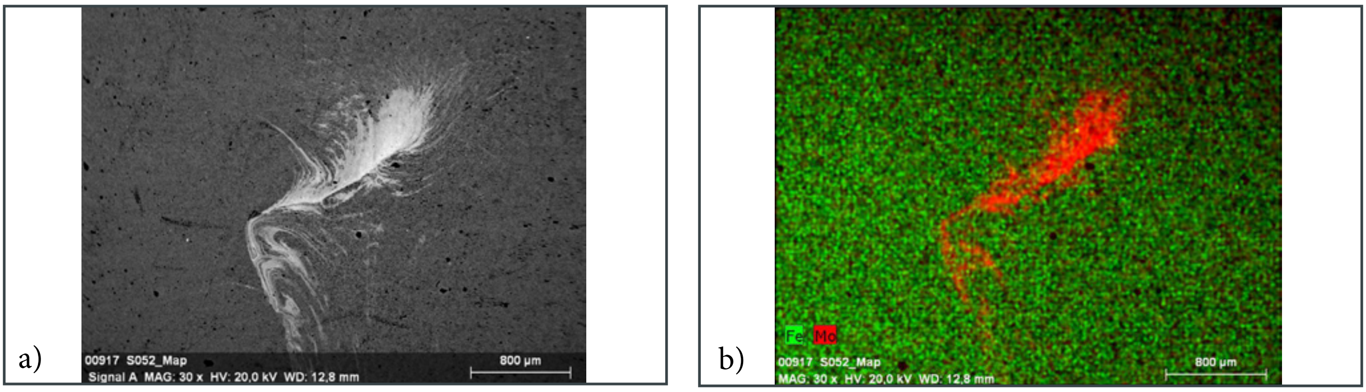


Figure 11: SEM-EDX analysis around the inhomogeneous zone on the AS of the FSW weld a) SEM picture and b) Fe-Mo mapping

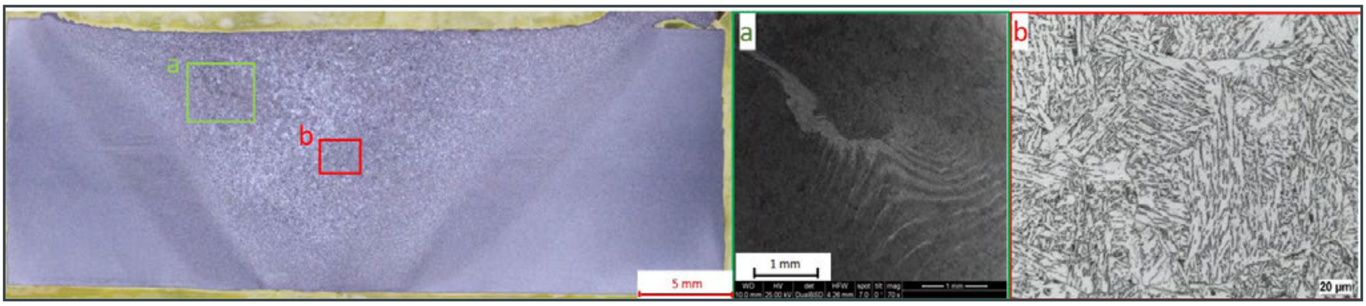


Figure 12: Characterization of the tool wear in a 15mm thick S460 G2+M weld seam performed with a W-based alloy tool.

Table 4: wt. % of tool wear elements on weld seams with Mo and W-based tools

		XRF-analysis [wt.%], advancing side	
Element	**Base metal S460 G2+M**	**Welded with Mo-based tool**	**Welded with W-based tool**
Mo	0,01	0,29	0,013
W	0,002	0,005	0,04

Table 4: wt. % of tool wear elements on weld seams with Mo and W-based tools

In the next step, the welding depth was increased to 15mm. For the increased welding thickness, the Mo-based tool was not capable to perform sound weld seams. The wear on the tool was too high and with the increased tool load associated to the higher welding depth the probe started to deform. Therefore, the tool material was changed to a tungsten-based alloy. The new tool material showed less wear and a higher rigidity.

This change led to an adaptation of the process parameters to achieve sound weld seams. Weld trials performed with the new tool still showed some tool wear in the weld seam, but the concentration was significantly lower. Figure 12 shows the microstructure of the weld center and the wear particle enriched zone on the advancing side.

To quantify the amount of wear on both tools, XRF-analyses by 10x10 mm spot on the advancing side of two weld seams have been performed (one with Mo and one with W-based tool). The results are given in Table 4. The increase in concentration for the weld seam performed with the Mo-based tool is 0,28 wt.% molybdenum versus 0,038 wt.% tungsten on the weld seam performed with the W-based tool compared to 0,01 wt.% molybdenum and 0,002wt% tungsten in the base metal.

To qualify the weld seam quality, additional mechanical tests have been performed. An example of an 5t bend (15mm S460 G2+M) test and a tensile test (10mm S460 G2+M), where the weld seam overmatched the base material according to DNVGL-ST-F101, are given in Figure 13 a) and b).[5]

Table 5 shows the micro hardness in the weld seam. The position of the measuring points was chosen according to DNVGL-ST-F101.[5]

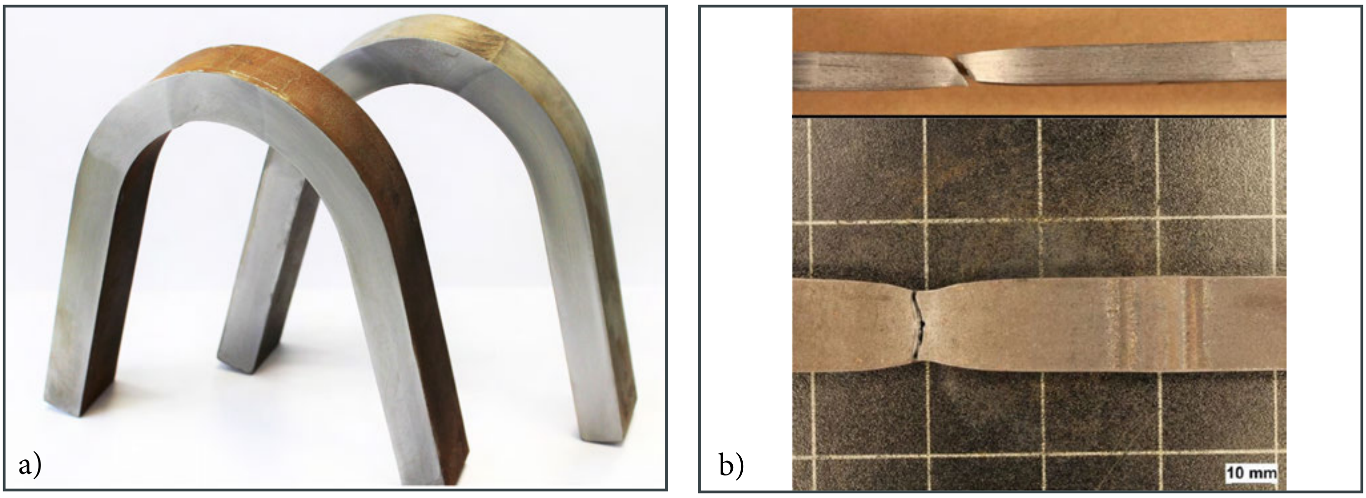


Figure 13: a) Root bend and face bend specimen of a 15mm S460 G2+M weld seam performed with a W-based tool and b) Tensile specimen from a 10mm S460 G2+M weld seam performed with a Mo-based tool

Table 5: Cross weld HV 10 hardness values for a 10mm S460 G2+M weld seam Mean hardness values HV10					
	Base metal AS	HAZ and TMAZ AS	Weld zone	HAZ and TMAZ AS	Base metal AS
cap	183	175	217	179	189
mid	177	177	206	177	179
root	177	172	204	175	180

Table 5: Cross weld HV10 hardness values for 10mm S460 G2+M weld seam Mean hardness values HV10

Figure 16: Cross section of a 14.3mm thick SMLS X65Q PSL2 pipe welded with a W- based tool

After achieving the required weld seam quality, the welding speed was increased up to 330 mm/min to decrease the weld cycle time and thus increase the cost saving potential. The welding speed was limited by the machine capacity.

4.5 S690 QL1 WELDING DEVELOPMENT

To show the potential of FSW on welding higher grade pipeline steel, the next step was to change to S690 steel grade. These changes in the base material led to some necessary changes in tool design, welding and preheating parameter. Comparing to the S460 weld trials, the higher steel grade tests were also performed on 10mm plates first and then the welding depth was increased to 15mm. After the W-based tool showed less wear and a higher stiffness in the previous work, the same material was used for this welding development. Compared to the 15mm thick S460 weld trials, the downforce was increased by 18% and the resulting spindle torque by 15% when welding 15 mm thick S690 steel grade. First visual inspection of the cross section of a 15mm thick weld seam indicated a higher tool wear on the higher steel grade. XRF analysis, shown in Table 6, confirmed this assumption. The amount of tungsten was 8.4 times higher on 15mm thick S690 compared to S460. After achieving flawless weld seams quality tests were started by checking the hardness values in the weld seam. The hardness profile, illustrated in Figure 14b shows a drop in the HAZ and thermomechanical affected zone and a slight increase in the weld zone (but still lower than the base metal).

Table 6: Tungsten wear in weld seams produced with W-based tools XRF-analysis [wt.-%], advancing side				
Element	Base metal S690 QL	Base metal S460 G2+M	15mm thick S690 QL welded with W-based tool	15mm thick S460 G2+M welded with W-based tool
W	0,002	0,002	0,126	0,015

Table 6: Tungsten wear in weld seams produced with W-based tools XRF-analysis [wt.-%], advancing side

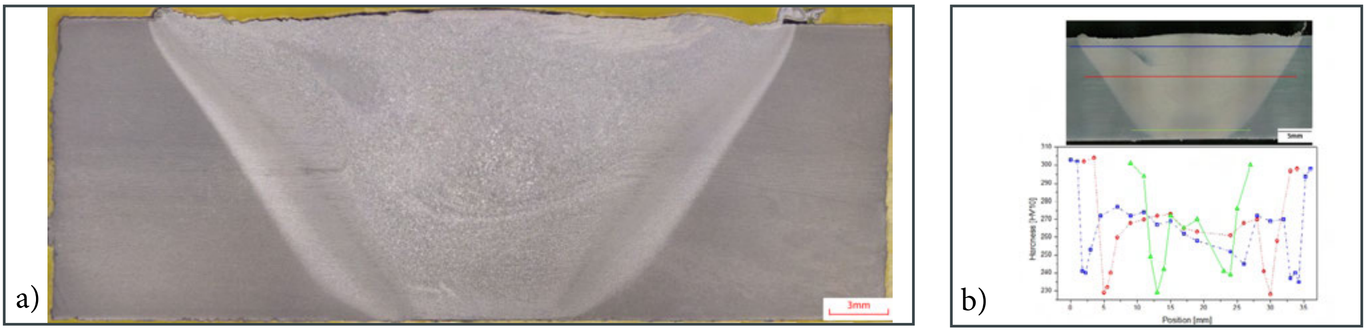


Figure 14 : a) Cross section of a 15mm S690 QL weld seam performed with a W- based tool and b) the related hardness values

4.6 PIPE WELDING ADAPTATION

The adaptation of the welding parameters developed on plate to circumferential pipe welding required 1) the development of the suitable welding equipment and backing system and 2) a sensitivity analysis on the transferability of the welding and preheating parameters from a flat to a curved surface.

In the initial stage of the pipe welding adaptation, it has been decided to opt for the AWS 1G welding position where the pipe is in the horizontal position and is rotated along its axis. The welding tool remains stationary as to its X and Y axis. During plunging and retraction, the tool can move along its Z axis. It can be noted that, although it is understood that a production-ready FSW pipe welding machine would have to be an orbital machine on a fixed pipe (AWS 5G/6G configurations), it is more convenient to use the 1G position during development work. The FSW process being virtually insensitive to gravity, a transfer between 1G to 5G/6G position is not anticipated as being an issue. The design of a backing system on pipe is more complex than on plate and required the design of an internal clamping device able to expand radially inside the pipe to provide a local support under the weld zone.

Table 7: Chemical composition of the pipe material (wt. - %)

Steel grade	C	Si	Mn	P	Cr	Ni	Cu	Mo	Ti
SMLS X65Q PSL 2	0,099	0,240	1,320	0,015	0,077	0,148	0,178	0,135	0,002

Table 7: Chemical composition of the pipe material (wt.-%)

The selected pipe material was an API 5L seamless X65Q PSL 2 of dimensions 323.8mm OD x 14.3mm WT. The pipe chemical composition is detailed in Table 7.
The reference welding parameters were based on the welding procedure established on plate 15mm S460 G2+M.

4.6.1 INITIAL TRIALS AT 10MM WITH MO-BASED TOOL

First trials were performed with the 10 mm Mo-based tool to check the comparability of plate and pipe welding behavior. The results showed a higher necessary welding force (downforce) to achieve the same results as on plates. This may be linked to the changes in thermal mass of the test setup (1400mm long pipes compared to 300mm wide plates) or the slight differences in the used materials (S460 G2+M plates compared to SMLS X65Q PSL2 pipes). After an increase of the downforce by 9%, good results were achieved. Figure 15 shows the resulting weld seam on a pipe.

4.6.2 14.3MM THICK SMLS X65Q PSL2 PIPE WELD TRIALS

With the knowledge of the different welding behavior between the weld trials on plates and on pipes from the

Figure 15: Weld bead on SMLS X65Q PSL2 pipe done with 10mm Mo-based tool

10mm Mo tool test, the full 14,3mm wall thickness was welded. Again, the tungsten-based tool was used for the higher welding depth.
Figure 16 shows a cross section of a 14.3mm thick SMLS X65Q PSL2 pipe welded with a tungsten-based tool. This part of the project is still ongoing and aims to reach the necessary weld seam quality according to DNVGL-ST-F101.

4.7 DISCUSSION

Less tool wear and higher hardness values and strength in the weld nugget may probably be achieved by decreasing the overall heat input during welding and preheating. However, this results in higher process loads and especially in a higher spindle torque that was initially limited by the machine's capacity. Sound friction stir welds on the 15mm thick S690 material could only be produced by utilizing an increased heat input by preheating at relatively low welding speeds. Higher welding speeds result in a higher radial and axial forces as well as spindle torques. In the present study, Mo-based FSW-tools seem to be unsuitable for joining of thick steels due to their susceptibility to deformation and abrasive wear. W-based tools seem more promising for such applications due to their improved hardness, strength and toughness at elevated temperatures. Nevertheless, certain tool wear could still be observed with both tools. The localized tungsten-rich zone on the advancing side of the weld can likely be prevented by using features such as threads on the probe. It is well known that, in such case, most of the wear occurs at the threads and is accelerated once features are used.6 This may markedly influence the stirring property and lifetime of the tool. If a tougher tool material (higher wear resistance) could be found, the use of features on the probe could be a promising option to improve the stirring. The process adaptation to pipe welding was possible thanks to the machine upgrade and the pipe rotator system and internal backing clamp. Further work is needed to develop the end hold extraction procedure on a curved surface.

5 CONCLUSIONS

The development program showed that friction stir welding for steel pipeline fabrication is a promising technology. Sound weld seams according the DNVGL standard were produced.5 One major point for optimization is the reduction of the tool wear. As shown in the paper, choosing the right tool material and the use of a preheating process can reduce it significantly. The preheating also affects the welding parameter and reduces the needed loads on the machine. The additional heat input from the preheating system reduces the amount of energy that must be generated by the tool. This has a direct effect on possible welding speed and machine design.

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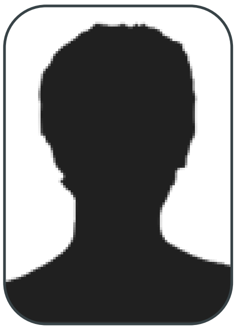
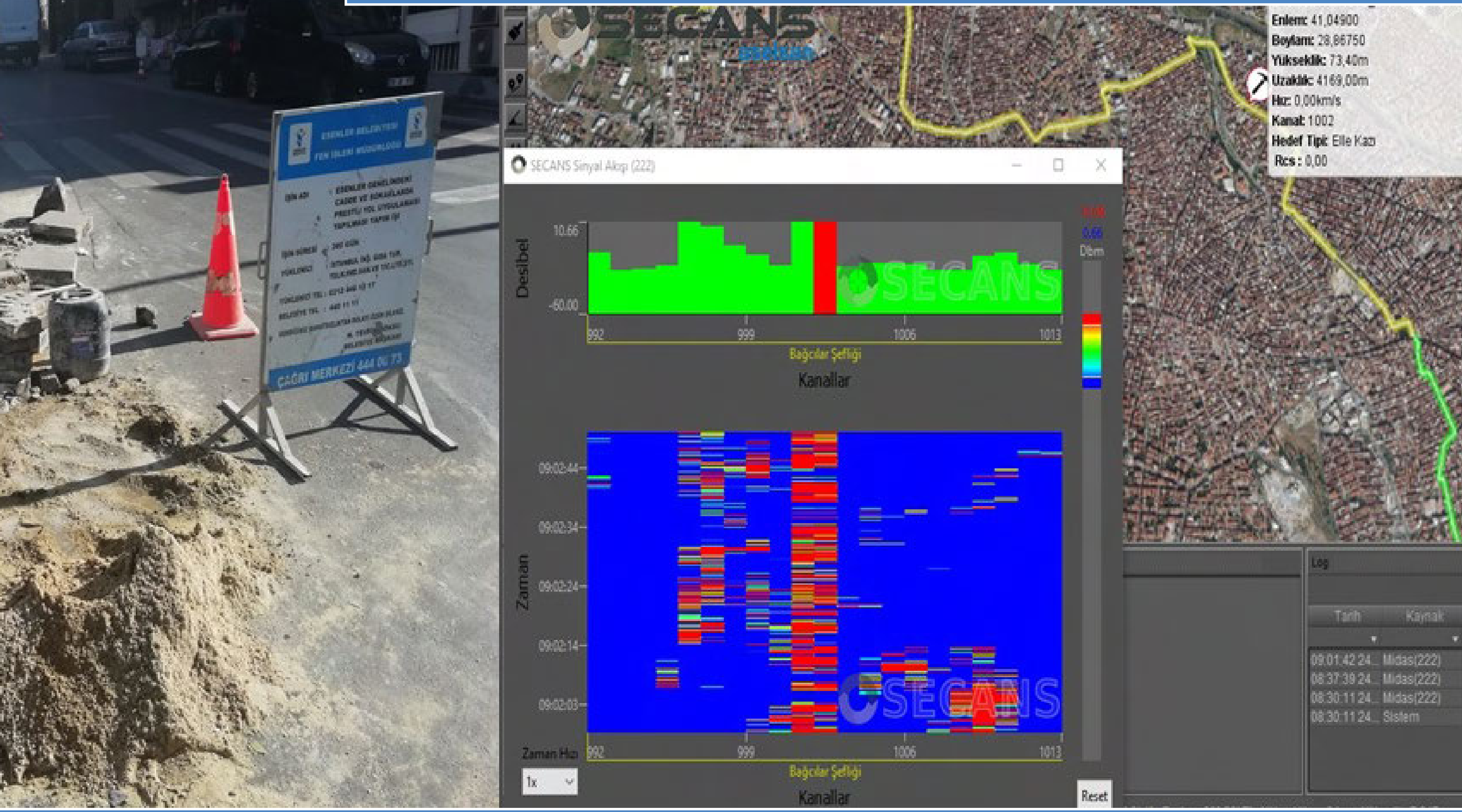


Machine Learning Approach to Distributed Acoustic Sensors (DAS) for Securing Pipelines in Urban Areas



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Abstract

Third party interference is one of the leading causes of pipeline failures and accidents that create great risk for safety and environment, as well as revenue loss for the operators. Especially in urban areas unauthorized and uncoordinated infrastructure and construction works pose serious threat to liquid and gas pipelines. Effective detection of intrusive activities and a timely preventative course of action is crucial. Fiber optic Distributed Acoustic Sensors (DAS) are useful and proven tools for third party interference detection.

Distributed Acoustic Sensing (DAS) is a sensing technology that uses standard telecommunications fiber optic cable that is buried parallel to the pipeline as an array of acoustic sensors. Detection and classification of intrusive activities in urban areas while minimizing nuisance alarm rates is a challenging problem due to high intensity urban activity noise. A robust solution in the urban environment requires multi stage machine learning (ML) approach that takes advantage of state-of-the-art sound activity recognition and anomaly detection algorithms.

We propose a three-stage interference detection algorithm. The first stage of the algorithm is sound recognition that classifies short sound clips with Convolutional Neural Networks (CNN). The second stage of the algorithm is model based event detection that recognizes activity patterns in series of audio clips. The final stage of the algorithm fuses data from multiple channels of the acoustic array to model moving vibration sources to reduce the nuisance alarms.

Proposed algorithm is deployed in highly populated urban areas for securing natural gas pipeline in Istanbul, Turkey. The system has successfully detected multiple instances of third-party interferences with a very low nuisance alarm rate.

1. INTRODUCTION

DAS is a sensing technology which converts vibrations on a standard fiber optic cable to an acoustic signal based on Rayleigh backscattering. Phase sensitive OTDR measurement technique is based on transmission of coherent light pulses in a fiber optic cable and measures the reflections from scattering centers which act like a mirror due to molecular imperfections in the cable. Arrival time of the reflections and the change in the received signal content allows classification of different activity types on estimated distance on the cable. As a result, received data can be represented as signals coming from an array of uniformly distributed acoustic sensors where the resolution and number of channels depends on the hardware components and computation capabilities [1].

DAS technology has been widely used in several applications such as pipeline monitoring and intrusion detection. For these applications, effective data processing techniques are required to transform received acoustic signals into highly accurate activity alarms with low nuisance alarm rate. Depending on the field and customers' demand, signal processing techniques can reach an acceptable performance in activity detection but highly accurate activity classification in noisy environments such as urban areas requires state of the art machine learning techniques.

Taking DAS sensor capabilities and the required tasks into account, machine learning techniques present promising results in various fields and applications. The general task, activity recognition for securing pipelines in urban areas, can be solved with divide and conquer approach which requires definition of smaller tasks. There are widely used ML techniques to solve some of these tasks but also some of them can be converted to a ML problem with an innovative perspective.

In this work, we proposed a 3 stage interference detection algorithm which combines widely used sound recognition technique with a model based algorithm to recognize activity patterns. In the last step of the proposed solution we followed an innovative approach to reduce nuisance alarm rate, by redefining the problem as an image recognition task where effective solutions can be found with ML techniques.

2. PIPELINE SECURITY IN URBAN AREAS

In general, interference detection systems are installed in rural areas to prevent thefts from the pipeline. These regions have low noise sources and it is easier to detect interferences in such field due to clear activity signals. Even though the low possibility of thefts in urban areas, involuntary damages due to infrastructural works occur very often. In rural areas the primary challenge of activity detection is the varying natural factors such as different soil types and weather conditions. In urban areas, artificial noise sources are added to the given environmental challenges. Traffic, human activities, lighting poles, crossing roads can be given as examples of noise sources in urban areas. Background noise in urban areas makes harder to detect activities and increases the false alarm rate. Maintaining the same detection rate as in urban areas requires additional nuisance alarm reduction algorithms.

For the pipeline security application in urban areas, infrastructural works must be detected at early stages. In general, one or more activities given below causes damages on pipelines.

- Asphalt cutting
- Breaker
- Driller
- Excavator
- Manual Digging

Figure 1: Map of a pipeline in a urban area

3. DATASET AND PERFORMANCE METRICS

In order to develop algorithms and to evaluate the performance of the system we need an extensive dataset with informative performance metrics. We have two different types of records and two different metrics corresponding to these two types. The first type of data is activity clips which are recorded covering activity location and neighbouring locations spanning 100 channels (10m wide), and these are used to examine detection rate. It is important to diversify the activity clips which are recorded in different fields for different activity types. We have 1000 activity clips collected from 5 different regions for 4 different activities. Also, it is important to have standard records to evaluate the performance objectively. Detection rate is calculated as the ratio of number of correct detections to number of records.

The second type of data consists of long records covering diverse geographical locations. We have long records from 5 different fields and the total duration of the records are 10 days for 5000 channels data. It is required to have normalized metrics therefore we take the proportion of alarm counts to number of channels times duration in terms of days. As a result, the false alarm rate gives an estimation of alarm counts in a day for 50 km.

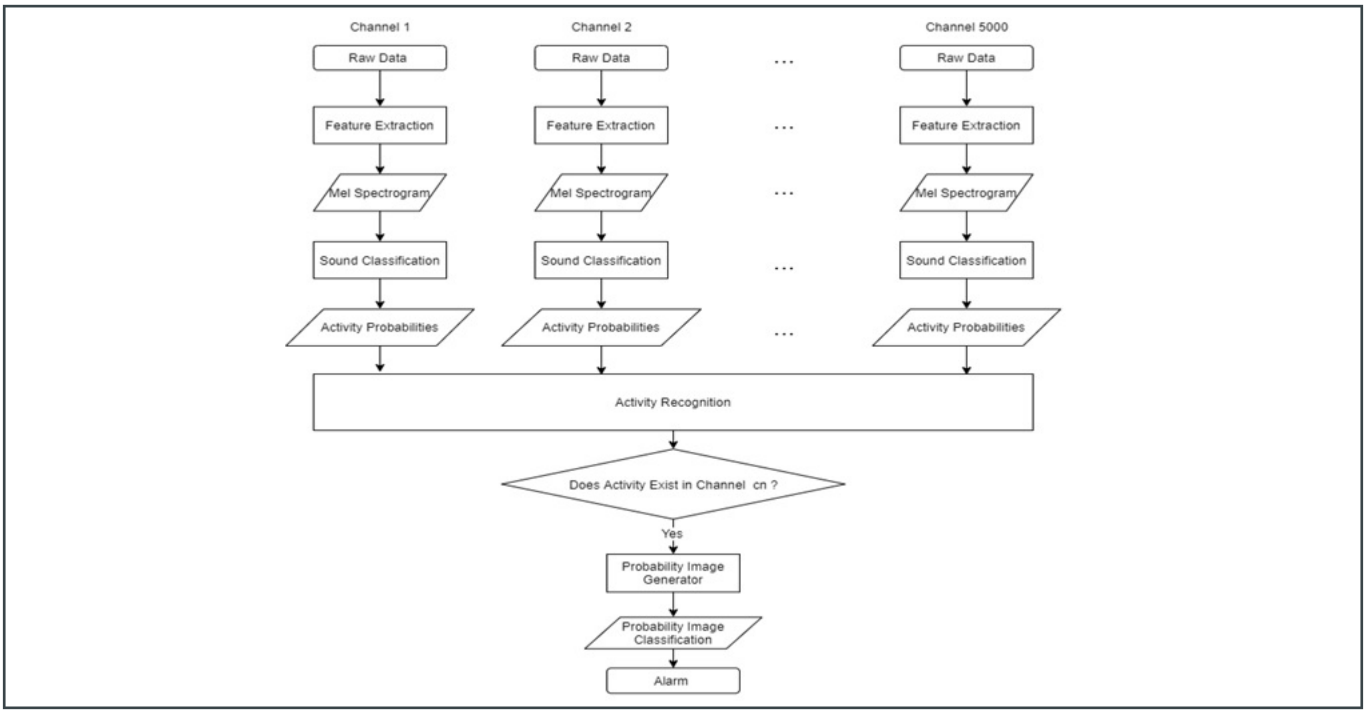

Figure 2: Data Flow Diagram

4. PROPOSED METHOD

4.1 STAGE 1 : SOUND CLASSIFICATION

The first stage is the sound classification of short clips in independent channels. CNN classifier on spectrogram images have been proved to be successful in sound recognition tasks [2]. For a DAS application, it is expected to classify different activities on varying soil types for different ranges and distance to cable. The goal of the classifier is to detect steps of the activity where a step can take 1-2 seconds approximately.

In sound classification with CNN classifiers, spectrogram representations are used as inputs of the CNN. Size of the spectrogram images depends on duration and frequency content of the target activities. Spectrogram images are good representation of sound activities but in general they have relatively large dimensions for image classification with neural networks. So filterbanks are used to represent spectrogram images with small losses. Mel filterbanks are commonly used in sound processing tasks which approximates the human auditory system's response. It reduces the height of the image from specified fft window size to, Nmels number of mel filterbanks.

CNN classifier inputs are *Nmels X Nhops* mel spectrogram images where *Nhops* is the number of hops. Spectrograms are computed for window size W, fft length L, hop length l, so that the spectrogram has *Nhops* = + 1 hops.

Also, Mel filterbank consists of Nmels $\frac{W-L}{l}$ filters specified between *fmin* and *fmax*. Mel filterbank provides a good representation with lower dimensions. Smaller receptive fields allow faster neural network computations which is necessary where spectrogram images are computed for each 200ms window for all channels which correspond to 5000 * 5 =25000 neural network computation per second.

Classifier has 5 different output classes, walking, digging, mechanical digging (2 classes) and noise. Instead of the different activity types, different patterns in observed signals are considered for output classes. As a result, many different excavator activities are clustered in 2 different classes due to their different frequency characteristics.

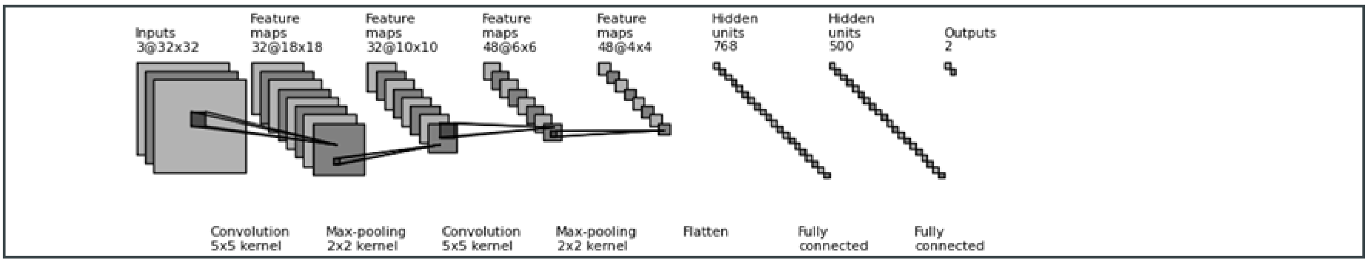

Figure 3: CNN architecture

For an input image, output is an array which shows the class probabilities as an array P = [Pdigging, Phuman, Pexc1, Pexc2, Pnoise]. In Figure 4, a sample spectrogram image is given. Output is [0.97 0.00 0.00 0.00 0.03] which means it is a digging image with high probability.

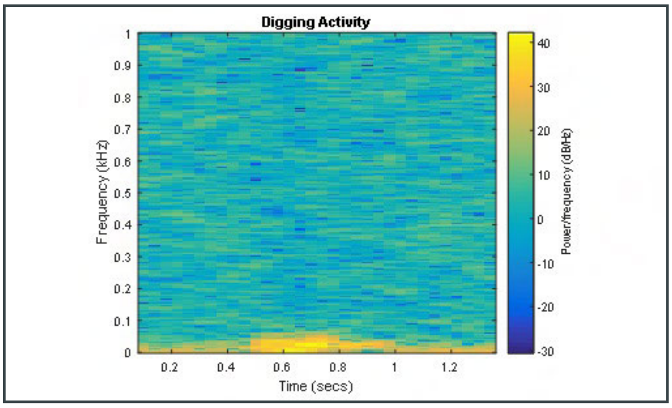

Figure 4: Manual Digging

4.2 STAGE 2 : ACTIVITY RECOGNITION

The second stage is activity recognition where an activity consists of meaningful patterns of several steps. Unlike the first stage, a model-based approach is followed in this stage. Model depends on activity defined by customers. Activity ratio p can be defined as the ratio of activity seconds to total duration. In general, an activity scenario can be defined with activity ratio p and activity window n, so that activity must be detected if the activity ratio is greater or equal to p in a window which has length n. For this stage it is important that the model must generalize well with a false alarm rate. Increasing p and n, decreases the false alarm rate but it causes missed detections if there are intermittent activities. Optimizing p and n requires an extensive dataset.

In urban areas it is useful to choose high p to decrease false alarm rates, but it can be adjusted adaptively depending on the noise level. We used adaptive thresholding which allows us to decrease activity ratio up to some level to decrease the detection time. Different features can be used as a parameter of adaptive thresholding. In general, it gives better results to use the statistics of adjacent channels to adjust adaptive thresholds.

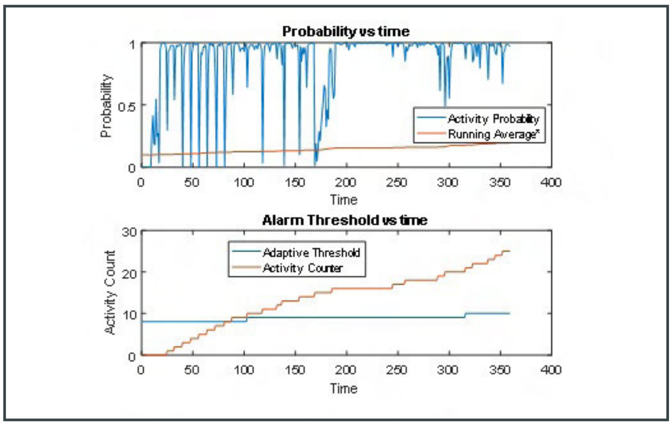

Figure 6: Adaptive Threshold

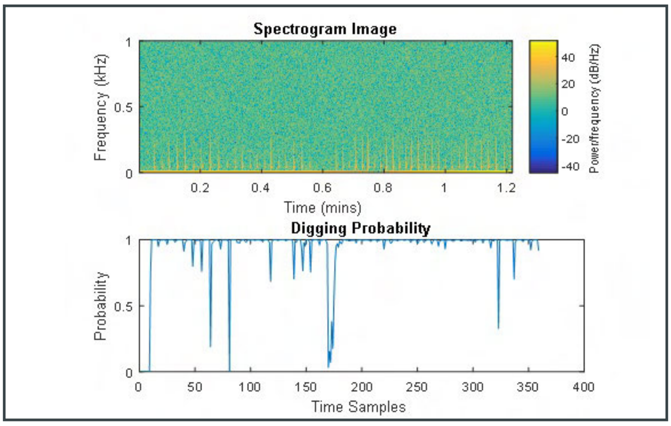

Figure 5: Probability Signal

4.3 STAGE 3 : PROBABILITY IMAGE CLASSIFICATION

The last stage of the algorithm is an innovative technique which exploits multiple channels data to reduce false alarms. In urban areas there are some noise patterns which can be easily recognized by the user. Inspired by this fact we tried to implement a binary classification algorithm based on deep learning. We used a CNN to differentiate natural noise patterns and activities.

Input data of the last stage consists of grayscale images of *NtsX Nchan* where *Nts*, *Nchan* represent number of time samples and number of channels respectively. Output of the neural network is a probability that shows whether the input comes from an activity or a known noise pattern. This neural network is activated for the events that passed the second stage, so the computation load is reduced.

For this neural network we generated a synthetic dataset. First, we clipped noise patterns from daily records which have high powers. Then we integrated activity patterns around the center channel of the images. This allows us to simulate activities for noisy environments.

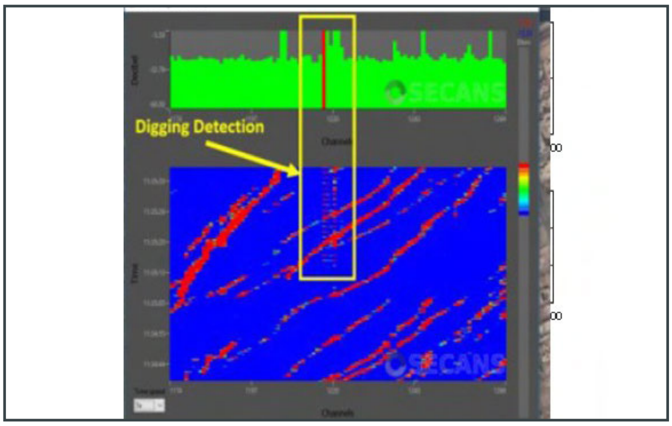

Figure 6: Probability Image Classifier

5. RESULTS

We will consider the detection rate and the false alarm rate for each stage and overall algorithm. For the detection rate, controlled experiments are conducted. For any alarms given by the system, security guards are directed to the field. False alarms are verified with the user's report according to feedback of security staff. As described in Section 2, we have 1000 activity clips for the detection rate and we have 10 days, 5000 channels data for the false alarm rate.

5.1 STAGE 1

	Walking	Digging	Excavator 1	Excavator 2	Noise
Walking	98	1	0	0	1
Digging	2	95	1	0	2
Excavator 1	0	0	96	1	3
Excavator 2	0	1	3	92	4
Noise	1	0	1	0	98

Table 1: Confusion matrix of sound classifier

5.2 STAGE 2

In stage 2 we optimized the parameters of adaptive thresholding to minimize false alarm rate while maintaining the same detection rate. False alarms are counted for 5000 channel in a day.

	Default	Adaptive Threshold
False alarm count	30	26

Table 2: False alarm count after Adaptive threshold

5.3 STAGE 3

In the stage 3, classification accuracy of neural network is 96%.

	Default	Adaptive Threshold	Classifier
False alarm count	30	26	12

Table 3: False alarm counts with Probability of Image Classifier

6. CONCLUSION

In recent years, DAS technology becomes the most commonly used technique in pipeline security. Also, the latest improvements in deep learning and machine learning, makes the performance of the acoustic classifiers close to human level. When DAS and ML comes together, cost effective solutions have been applied in pipeline security. In this work we focused on pipeline security in urban areas where the high noise levels cause high false alarm rates. In order to keep false alarms under a certain level, we implemented a 3 stage algorithm. As a result, we achieved to decrease false alarm rates up to 60% while maintaining the same detection rate.

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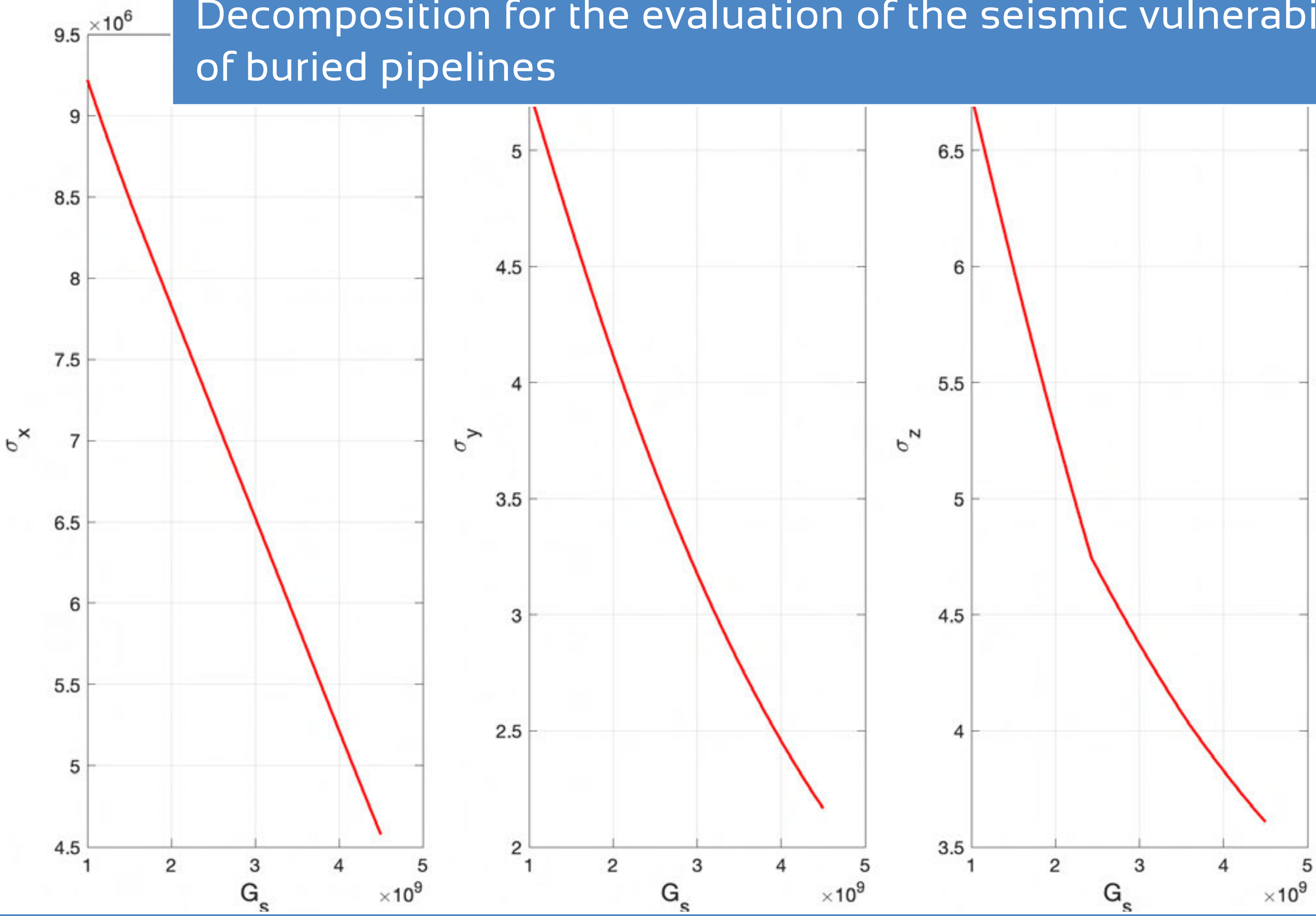
A new parametric study based on the Proper Generalized Decomposition for the evaluation of the seismic vulnerability of buried pipelines



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Abstract

Pipelines related to industrial supplies such as oil or gas are a key part of modern development, so it is important to ensure their appropriate response to a seismic action. The same applies to drainage or water supply in contemporary cities. Structural analysis of pipelines is a well-established topic in engineering practice. In this paper, we will present the application of the methodology Proper Generalized Decomposition (PGD) to the numerical analysis of buried pipelines, in order to obtain a parametric solution based on material properties. A new well-established method to compute the safety of buried pipelines is develop, based on a 3D finite element approach for computing a fine enough solution while circumventing the difficulties related to the excessive degrees of freedom of fully 3D mesh-based discretization, we took advantage of in-plane-out-of-plane separated representations within PGD. Those results can be used to safety evaluation, maintenance and protection of buried pipelines crossing seismic area. The solution can be evaluated in real-time from the offline construction of a parametric solution to the associated problem within the PGD framework.

1. INTRODUCTION

Ground shaking is the most familiar effect of earthquakes. It is a result of the passage of seismic waves through the ground, and ranges from quite gentle in small earthquakes to incredibly violent in large earthquakes. The seismic vulnerability of buried pipelines is demonstrated in many seismic events around the world. However, the causes of structural or geotechnical failures are cause for uncertainty and, therefore, extensive investigations have been carried out or are being carried out to reveal this problem. Lifelines, classified as energy systems, water treatment, transportation and information systems, are greatly affected by three major causes, including ground conditions, seismic scale and intensity, and lifeline features [1].

City underground pipeline systems have been suffered severely destroys in recent earthquakes, such as Horthridge earthquake of California [14] (USA, 1994), Kobe earthquake (Japan, 1995) and Ji-Ji earthquake (Taiwan, 1999) [4]. Not only normal usage functions of underground pipeline systems are damaged directly, but also derivative calamities are brought.

Nowadays in modern pipe networks, whether on land or offshore, they are usually buried to provide them with greater protection and support. In addition, these may also require design for external loads, for example, loads imparted by heavy equipment on the ground surface, soil weight pressure, etc. This forces are statically undetermined because the soil characteristic is not uniform [15] It is impossible to accurately estimate the seismic behavior of a pipe due to the uncertainty of soil characteristics and seismic load. Therefore, it is necessary to evaluate the behavior of the static and seismic pipe to determine its behavior. The pipeline must be able to withstand both the effects of static loads like those due to self-weight or earth pressure as well as the different types of dynamic loads during a seismic event like those due to wave propagation or fault displacements.

During earthquakes, a buried pipeline can experience significant loads as a result of large relative displacements of the earth along its length. Large earthworks can be caused by faults, liquefaction, lateral displacement, landslides and slope failures, exposure to these hazards can be minimized by careful selection of a pipe route and proper analysis, especially in the case, these conditions are located in fault zones. However, faults and liquefaction induce other movements, such as lateral expansion, since it is often not possible to avoid such long pipe routes through areas of high seismicity.

In this research, a new parametric study based on the Proper Generalized Decomposition (PGD) is develop to illustrate the influences of material parameters, related to soil and pipeline, on the structural response of buried pipeline. The results can be used to safety evaluation, maintenance and protection of buried pipelines crossing seismic area.

2. ELASTICITY PROBLEM. IN PLANE OUT OF PLANE SEPARATED REPRESENTATION

Authors have recently proposed a powerful new discretization technique based on the use of separated representations called Proper Generalized Decomposition, which demonstrates their ability to solve multidimensional models. This technique works by building separated representations of the solution, in that way, the complexity scales of the solution are linear with the dimension of the space in which the model is defined, instead of exponentially growing complexity of the mesh, based on commons discretization techniques. The PGD methods allows the efficient solution of the models to be defined in multidimensional spaces such as those found in quantum chemistry, kinetic theory descriptions of complex fluids, genetics, etc. For problems where the norms are defined in space and time, we add new coordinates resulting numerous possibilities.

The method consists of introducing model parameters as extra coordinates, in the same way that time and space were originally defined in the problem. The problem is then solved once for all the coordinates allowing circumvent the so-called curse of dimensionality. The interested reader can also refer to the recent reviews [5] [6] [7] [11].

In what follows we describe the construction of the parametric solutions within the Proper Generalized Decomposition framework. We considered the in-plane-out-of- plane decomposition for solving 3D problems in plates. In [3] is considered the in- plane-out-of-plane decomposition for solving 3D elastic problems in plate geometries. The separated representation of the displacement field $U = (u, v, w)$ reads:

$$\boxed{U(x,y,z) = \begin{pmatrix} u(x,y,z) \\ v(x,y,z) \\ w(x,y,z) \end{pmatrix} = \sum_{i=1}^{N} \begin{pmatrix} X_u^i(x,y)\cdot Z_u^i(z) \\ X_v^i(x,y)\cdot Z_v^i(z) \\ X_w^i(x,y)\cdot Z_w^i(z) \end{pmatrix}}$$

$$= \sum_{i=1}^{N} \mathbf{X}^i(x,y) \circ \mathbf{Z}^i(z)$$

where "*o*"stands for Hadamard (component –wise) product. Vectors X^i are the functions in the plane (x, y) and Z^i are the functions involving the thickness (z). Is important to know that the above functions are not known a priori but are calculated by the same method by introducing the separated representation of the solution in the weak formulation of the problem resulting in a nonlinear problem. This implies that iterations are needed at each enrichment step. The weak formulation of the dynamics elasticity problem in a body Ω writes as follows:

$$-\int_{\Omega} U^{*t}\rho\omega^2\, U\, d\Omega + \int_{\Omega} \varepsilon^{*t} D\varepsilon\, d\Omega = \int_{\Omega} U^{*t}F\ \ d\Omega$$

where the domain $\Omega = \Omega xy \times \Omega z$ with $(x, y) \in \Omega xy$ and $z \in \Omega z$. The linear elastic isotropic material is given by the generalized 6 x 6 Hooke tensor:

$$D = \begin{bmatrix} \lambda+2\mu & \lambda & \lambda & 0 & 0 & 0 \\ \lambda & \lambda+2\mu & \lambda & 0 & 0 & 0 \\ \lambda & \lambda & \lambda+2\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu \end{bmatrix} \qquad \lambda = \frac{vE}{(1+v)(1-2v)} \qquad \mu = \frac{E}{2(1+v)}$$

where E is the young modulus, v the Poisson coeficient, p the density and F is the volumetric body forces. We use the following definitions to the strain vector

$$\varepsilon = \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{xz} \\ \gamma_{yz} \end{bmatrix} \qquad \begin{aligned} \varepsilon_x &= \frac{\partial u}{\partial x} = \sum_{i=1}^{n-1} \frac{\partial X_u^i}{\partial x} Z_u^i \\ \varepsilon_y &= \frac{\partial v}{\partial y} = \sum_{i=1}^{n-1} \frac{\partial X_v^i}{\partial y} Z_v^i \\ \varepsilon_z &= \frac{\partial w}{\partial z} = \sum_{i=1}^{n-1} X_w^i \frac{\partial Z_w^i}{\partial z} \end{aligned} \qquad \begin{aligned} \gamma_{xy} &= \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} = \sum_{i=1}^{n-1} \frac{\partial X_u^i}{\partial y} Z_u^i + \frac{\partial X_v^i}{\partial x} Z_v^i \\ \gamma_{xz} &= \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} = \sum_{i=1}^{n-1} X_u^i \frac{\partial Z_u^i}{\partial z} + \frac{\partial X_w^i}{\partial x} Z_w^i \\ \gamma_{yz} &= \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} = \sum_{i=1}^{n-1} X_v^i \frac{\partial Z_v^i}{\partial z} + \frac{\partial X_w^i}{\partial y} Z_w^i \end{aligned}$$

Supposing that U^{n-1} to be known, we focus on the solution enrichment related to the computation of the next functional product $X^n(x, y)$ and $Z^n(z)$, according to:

$$U(x, y, z) = U^{n-1}(x, y, z) + \begin{pmatrix} X_u^n(x, y) \cdot Z_u^n(z) \\ X_v^n(x, y) \cdot Z_v^n(z) \\ X_w^n(x, y) \cdot Z_w^n(z) \end{pmatrix}$$

or

$$U(x, y, z) = U^{n-1}(x, y, z) + \mathbf{X}^n(x, y) \circ \mathbf{Z}^n(z)$$

The test function U^* reads

$$U^*(x, y, z) = \begin{pmatrix} u^*(x, y, z) \\ v^*(x, y, z) \\ w^*(x, y, z) \end{pmatrix} = \begin{pmatrix} X_u^*(x, y) \cdot Z_u^n(z) + X_u^n(x, y) \cdot Z_u^*(z) \\ X_v^*(x, y) \cdot Z_v^n(z) + X_v^n(x, y) \cdot Z_v^*(z) \\ X_w^*(x, y) \cdot Z_w^n(z) + X_w^n(x, y) \cdot Z_w^*(z) \end{pmatrix}$$

Finally, introducing Eq. (1), Eq. (4) and Eq. (6) into the Eq. (2) the resulting weak form reads now

$$\begin{aligned} &-\int_{\Omega} [u^*\rho\omega^2 u + v^*\rho\omega^2 v + w^*\rho\omega^2 w]\, d\Omega \\ &+ \int_{\Omega} [\varepsilon_x^* \Theta \varepsilon_x + \varepsilon_y^* \lambda \varepsilon_x + \varepsilon_z^* \lambda \varepsilon_x + \varepsilon_x^* \lambda \varepsilon_y + \varepsilon_y^* \Theta \varepsilon_y + \varepsilon_z^* \lambda \varepsilon_y + \varepsilon_x^* \lambda \varepsilon_z \\ &+ \varepsilon_y^* \lambda \varepsilon_z + \varepsilon_z^* \Theta \varepsilon_z + \gamma_{xy}^* \mu \gamma_{xy} + \gamma_{xz}^* \mu \gamma_{xz} + \gamma_{yz}^* \mu \gamma_{yz}]\, d\Omega \end{aligned}$$

where $\Theta = \lambda + 2u$. The introduction of Eq. (5) into to (7) results a non-linear problem. We proceed by considering the simplest linearization strategy, an alternated directions fixed point algorithm, that proceed by assuming sequentially that $Z^{n,p-1}(z)$ is known of the previously iteration, and proceed to compute $X^{n,p}(x, y)$. Finally with $X^{n,p}(x, y)$ is computed $Z^{n,p}(z)$. The process is repeated in a suitable fixed-point iteration scheme, until reaching convergence, where the results will be the new products $X^n(x, y)$ and $Z^n(z)$. The enrichment stop when the model residual become small enough.

First, we assume $Z^n(z)$ to be known from the previous iteration, in this case the test function is $U^* = X^*(x, y) \circ Z^n(z)$. Introducing the separated representation of the solution at iteration n (Eq. 5) and the test function into Eq. (6) and then integrating in Ωxy, the resulting 2D equation can be interpreted as the weak formulation in which we can obtain the unknown function $X^n(x, y)$, that can be solved by using any suitable discretization techniques.

Finally, with the new value of $X^n(x, y)$, the test function is chosen equal to $U^* = X^n(x, y) \circ Z^*(z)$. By introducing the (Eq. 5) and the test function into the weak formulation (Eq. 7) and integrating in Ωz, we obtain the resulting 1D weighted residual form that can be solved by using any discretization technique to obtain the unknown function $Z^n(z)$.

2.1. PROPER GENERALIZED DECOMPOSITION-BASED PARAMETRIC SOLUTIONS. CASE APPLICATION

In this section, we describe the parametric solutions within the Proper Generalized Decomposition framework. The model is assumed composed of ζ materials δ_j, i = 1, ... , ζ, the one related to the soil and the one related to the pipeline, in the same way, we can considered that the soil is composed for different layers which can be considered in the formulation as different materials. Each material is identified from its characteristic function $x_j(\alpha)$, $i = 1, \cdots, \zeta$, defined as

$$\chi_i(\alpha) = \begin{cases} 1 & \text{if} \quad \alpha \in \delta_i \\ 0 & \text{if} \quad \alpha \notin \delta \end{cases}$$

where α is the plane domain. The resulting weak form (Eq. 7), reads now

$$\begin{aligned} &-\int_{\Omega} [u^*(\rho_s\chi_s + \rho_p\chi_p)\,\omega^2 u + v^*(\rho_s\chi_s + \rho_p\chi_p)\,\omega^2 v + w^*(\rho_s\chi_s + \rho_p\chi_p)\,\omega^2 w]\, d\Omega \\ &+ \int_{\Omega} [\frac{\partial u^*}{\partial x}(\theta_s\chi_s G_s + \theta_p\chi_p E_p)\frac{\partial u}{\partial x} + \frac{\partial v^*}{\partial v}(\lambda_s\chi_s G_s + \lambda_p\chi_p E_s)\frac{\partial u}{\partial x} \\ &+ \frac{\partial w^*}{\partial z}(\lambda_s\chi_s G_s + \lambda_p\chi_p E_p)\frac{\partial u}{\partial x} + \cdots]\, d\Omega \end{aligned}$$

where the domain $\Omega = \Omega xy \times \Omega z \times \Omega \omega \times \Omega G_s \times \Omega p_s \times \Omega E_p \times \Omega p_p$, with s and p are related to the soil and pipeline and G is the shear modulus of soil.

The PGD solution in the separated form is

$$U(x, y, z, \omega_1, G_s, \rho_s, E_p, \rho_p) \approx \sum_{i=1}^{N} \mathbf{X}^i(x,y) \circ \mathbf{Z}^i(z) \circ \mathbf{W}^i(\omega) \circ \mathbf{G}^i(G_s) \circ \mathbf{P}^i(\rho_s) \circ \mathbf{E}^i(E_p) \circ \mathbf{r}^i(\rho_p)$$

The PGD procedure can be implemented as just described.

3. NUMERICAL EXAMPLE

In this section, a numerical example for illustrating the potentialities of the technique just proposed are presented. The PGD method was used to calculate the parametric solution of the displacement field u,v,w for all the combinations of the parameters $U(x, y, z, \omega_1, G_s, \rho_s, E_p, \rho_p)$. The problem coordinates are defined in the domains Ωxy = [0, 6] mts, Ω_z = [0, 5] mts, $\Omega_\omega = 2\pi(0{,}25)s^{-1}$, Ω_{G_s} = [1000, 4500] MPa, Ω_{ρ_s} = [1000, 2000] kg/m3, Ω_{E_p} = [200, 2E6] MPa and Ω_{ρ_p} = [1000, 7800] kg/m3. The pipeline elastic modulus and density were taken considering the values in table 1. The different domains were discretized by considering respectively 1388, 500, 1024, 200 100, 200 and 100 nodes. We considered a pipe with 1 mt diameter and 1% thickness, buried at a depth of 1 mt (see Fig. 2). The maximum acceleration is scaled for different values from a_{max} = [0.1 0.8] g.

Material	Elastic modulus MPa	Density kg/m^3
Polyethylene (PE)	200-400	920-960
PVC	3000	1370 -1420
Polypropylene (PP)	1200-1800	900
Concrete	2E4-4E4	2300
Steel	2.1E5	7800

Table 1: Pipeline properties for different materials

An approximate analysis is carried out on soil applying a linear analysis in which the properties as shear modulus (G) and damping ratio (ζ) are considered constant regarding with the level of deformation. In the case of a simple harmonic motion, damping can conveniently be expressed by using the concept of complex stiffness. The linear model represents the soil's stress–strain response using a Kelvin–Voigt model, in which a complex shear modulus G^* is considered, given by $G^* = G(1 + 2i\zeta)$, with $\zeta = 5\%$. In soil analysis, the control is defined from the response spectrum, or its corresponding time history, at bedrock by what is known as rock outcropping motion.

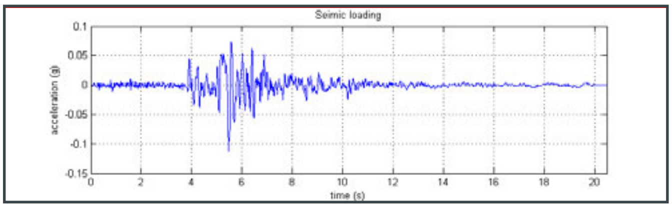

Figure 1: Seismic loading

From the outcropping motion, the objective is to predict the bedrock motion covered by the soil deposit. Thus, the bedrock half-space can be substituted with boundary condition

$$\tau^*_o = c_{s*}\rho_b A U_s - c_s A \rho_b U^*_{o}$$

where U_s the rock outcropping velocity (assumed measurable) and U^* the velocity at the base of the soil column [8] [9], that coincides with the soil-bedrock half-space interface and T^* the shear stress at that position. The solution is obtained assuming we know the acceleration time history in the outcropping, shown in Fig. 1 and has a dashpot at bedrock ρ_b = 2202 \ m3 and G_b = 3336 10 Pa with $c_{s^*} = \sqrt{G_s/\rho_b}$. The local transmitting boundary based on the formulation by Lysmer and Kuhlemeyer [9] is used for the infinite element in ABAQUS in order to minimize wave reflections from the boundary of finite element domains. The incident waves are absorbed at the boundary by many infinitesimal dashpots, which are orientated normal and tangential with respect to the boundary. These are designed to absorb plane waves, considered independently in three directions, by defining distributed equivalent dampers on the boundary. These can be defined in terms of load coordinates (x, normal and y, z tangential) as [13]

$$\tau_{xx} = c_p \rho i \omega u$$

$$\tau_{xy} = c_s \rho i \omega v$$

$$\tau_{xz} = c_s \rho i \omega w$$

where p is the material density, c_s the S-wave (shear wave) and c_p are the wave speeds of the P-wave (longitudinal wave), with $c_p = \sqrt{\lambda + 2G/\rho}$. These relations can be derived by assuming linear elastic stress-strain relations and zero wave reflection at the boundary for an incident plane wave of each type. In reality the incident field is not a plane wave and this leads to some residual reflection from the boundary [9].

4. RESULTS

This section shows the numerical capabilities of the numerical algorithm for computing a fine enough solution while circumventing the difficulties related to the excessive degrees of freedom of fully 3D mesh-based discretization, we took advantage of in-plane-out-of-plane separated representations within the Proper Generalized Decomposition (PGD) framework that permitted capturing details of the mechanical fields along the thickness.

Figure 3 illustrate the maximum displacement values versus the pipeline elastic modulus, taking into account the

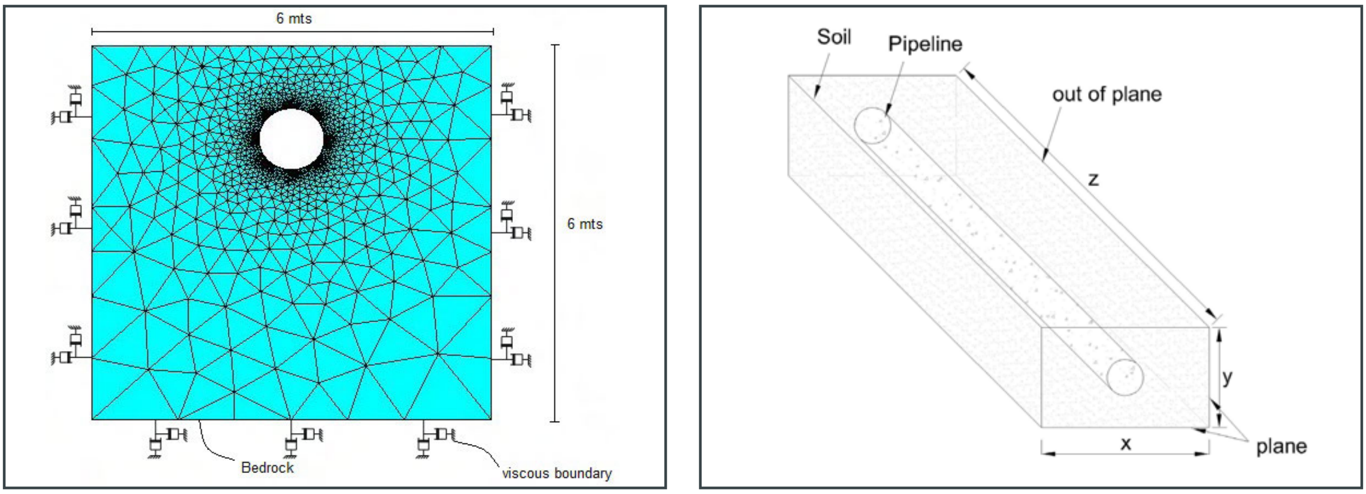

Figure 2: Pipe-soil model mesh and boundary condition

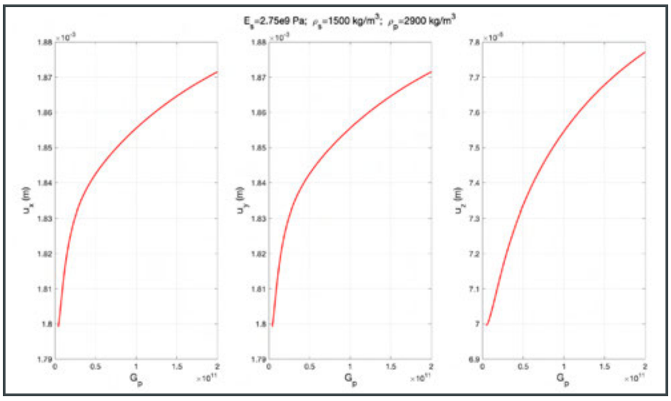

Figure 3: Maximum Displacement vs E_p (Pipeline Elastic Modulus)

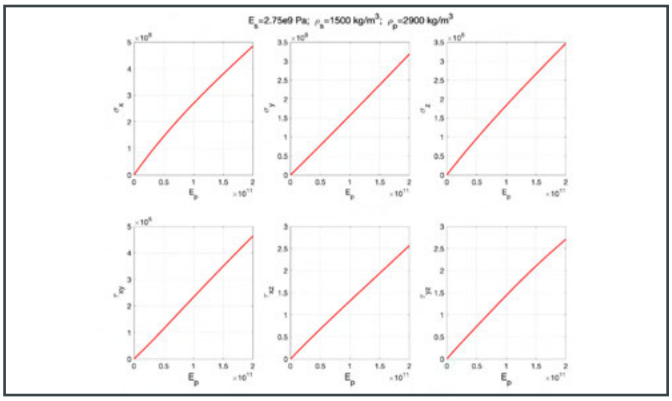

Figure 4: Maximum Stresses vs E_p (Pipeline Elastic Modulus)

constant values of the G_S = 2.75E9 Pa, p_S = 1500 kg/m^3 , p_P = 1900 kg/m^3 and a_{max} = 0.12 g, these results are taken from the top (x-y axes) and in the middle (z axe) of the pipeline. We can observed that the displacement values increase regarding the elastic modulus of the pipelines that varies from polyethylene to steel values. The maximums stresses versus the pipeline elastic modulus are shown in Figure (4), we can observe that normal and tangential stresses increase as the elastic modulus increases.

Figure 5 depict the maximum normal stresses versus the soil elastic modulus, taking into account the constant values of E_P = 1E10 Pa, p_S = 1500 kg/m^3 and p_P = 1900 kg/m^3, in this case the stress values decrease regarding the shear modulus of the soil.

The advantage of the PGD method is we could compute offline the parametric solution for the soil-pipeline model, for all parameter of the model, as soon as such parametric solutions are available, with the computational vademecum we can particularize in real time. The amount of memory required to store in the solution is negligible compared to what would have been required to store it on an equivalent three-dimensional grid.

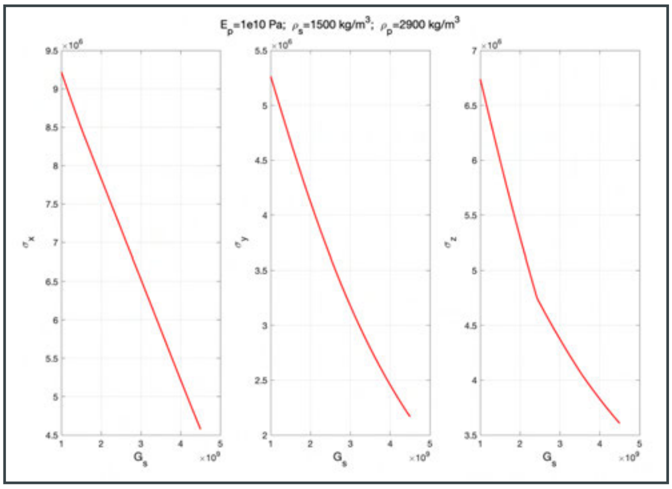

Figure 5: Maximum Stresses vs G_S (Soil Shear Modulus)

5. CONCLUSIONS

This paper proposes a new dynamic calculation for buried pipeline considering the soil interaction able to compute very fast solutions regarding different material parameters. This method can be used to identify suitable material combinations based on their potential stress reduction and displacements. The numerical algorithm capabilities for computing a fine enough 3D solution is based on the use of in-plane-out-of-plane separated representations within the Proper Generalized Decomposition (PGD) framework that permitted capturing details of the mechanical fields along the thickness. Model parameters have been considered as extra-coordinates for constructing parametric solutions that can be seen as computational vademecums from which we can perform in real time, optimization, inverse analysis and simulation based control. As a future work is on development a nonlinear soil behaviour and consider pipeline diameter as extra coordinates.

ACKNOWLEDGMENTS

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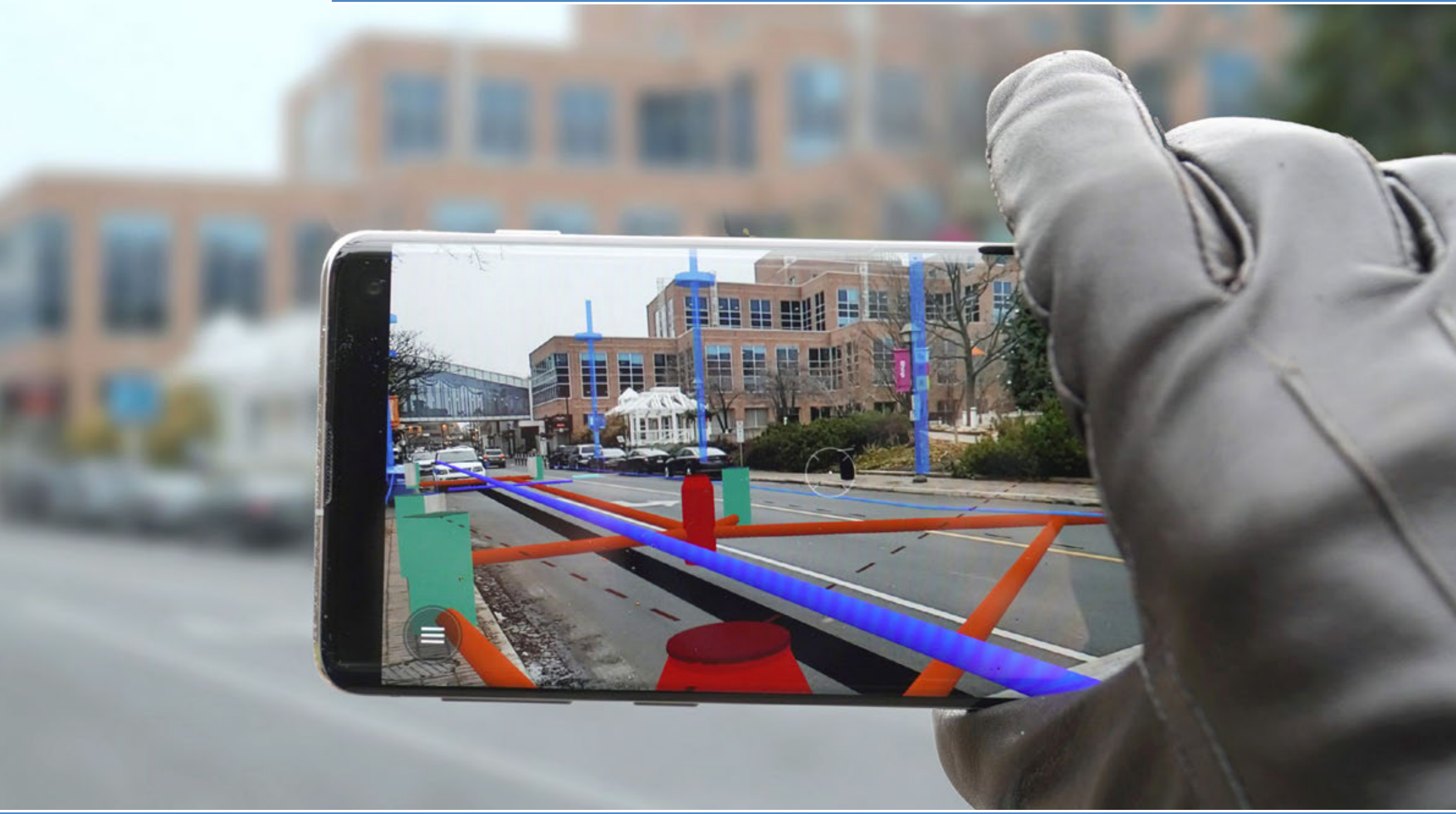

Yogin Gajjar > GSPL India Transco Ltd.

Abstract

A pipeline network is the most efficient and economical means of transporting hydrocarbons. Pipeline Operator's objective is to operate and maintain pipeline network in such a way that it would continuously provide uninterrupted services to customers. Locating underground pipes and other infrastructure prior to excavation or repair has long been a problem. While tremendous development has taken place in the field of locating technologies over the past decades, no one method has emerged as being complete. Errors in locating excavations for new installation or for repair of existing utilities can result in significant costs, loss of life and damage to property. There is thus a clear need for new solutions to accurately located pipeline infrastructure and improve excavation safety. This paper describes combination of Geospatial database of pipeline along with augmented reality to design a new visual system.

3D models of pipelines and other underground utilities are created from available geospatial data and then superimposed over normal real world view using geo-referenced Augmented Reality (AR) to provide the operator with the visual information on the location and type of utilities that exist underground. This system uses smart phone for android platform. Based on the location of the operator, all the pipeline and related information will be visualize on the mobile screen. System will provide pipeline information like Pipe dimension, pipe type, joint number etc., other utilities like foreign pipelines, OFC cable etc. with the detailed information, this will help operator to know and understand the exact underground information of particular location. The system ensures efficiency of management through a centralized structure and enables immediate visualization of AR data and minimizes the error range by using geographical information data that will lead to enable the strategic support for immediate response to irregular accidents.

1. INTRODUCTION

Due to geospatial environment of an underground utility, this paper which contains a suitable application of the augmented reality, provides realistic information of an environment of the underground utilities by converging invisible underground utilities with GIS data to augmented reality.

The proposed technology can manage to change accurate location information of various underground utilities into a database, and to design and develop a system that can analyze the data and generate results. Accordingly, the proposed system can enhance sense of reality and efficiency by converging efficient management of underground utilities with a real time monitoring technology.

2. TECHNOLOGY - AUGMENTED REALITY AND GIS

Augmented Reality (AR) is a technology which shows a view of the real world merged upon a digital image in real time, and provides users with more improved sense of reality. In particular, mobile AR is a technology which serves the information about the object and environment the user sees at present by converging it on the screen of a mobile device. By popular use of smartphones, mobile AR combines information about diverse sensors (slope, azimuth), focused on display field, situational recognition through input/output devices and hardware control, and thus studies on AR with this technology have been popular.

Based on this, diverse applications are developed through mobile AR technology by managing geographical information data converged with GIS (Geographical Information System) and by newly processing the data through collecting and analyzing.

3. GENERATION OF UNDERGROUND UTILITY INFORMATION USING AR

This paper is discuss about the system which control the geospatial data in underground utilities, and the key content, if the location is selected, is about the technique which can produce output of the underground utilities information of the location by analysing the information about the pipes, water pipeline, optical fiber cable buried underground. The resulting output display utility information with reference to the road and when a displayed area is selected, it shows the status information of the cross section by cutting the selected area of the road vertically.

For the accurate generation of AR based information following system design stages are involved:

I) Design the Database: For the detailed and accurate output of the data, it is require to manage and store detailed attributable information of each utility. There are multiple types of utilities are present at underground like water pipeline, gas pipeline, optical fibre cable and power lines. Also, all these utilities run through the underground with different lengths and diameters. The location of the utility is the most important information. AR based output cannot be generated without an information about its latitude and longitude. There should be additional information about the burial depth.
All utilities are judged as a model in the form of a matchstick and a marker is generated at the front end of each utility and the data is generated based on the information of the location at the beginning part of the marker.
The data fields components to generate detailed information about underground utilities are Utility unique number, Section of pipeline, Type of Utility, Length of Utility, Diameter of pipe, Latitude, Longitude, Depth of Utility, Remarks.

II) Design a System for generating Utility information: The database has been established and systemized which was designed by the above specs. An automatically generated system of the underground utilities has been designed using AR technology applied on a mobile terminal. The system has been built to enhance the user's accessibility even through the complexity of internal interface is increased. A block diagram and an interface of each system are as follows:

The System block diagram consists of AR module, Manage Server, Automatic Generation system of Underground utilities. AR module displays augmented reality techniques. Manage Server manages total data of utility information, constructs database. When user requires specific work, Automatic Generation of System performs event processing functions.

III) AR data generation system interface: The interface process of analyzing and extracting the contents of database fields and of generating a utility information using AR technology on the screen of a mobile device is as per above flows of information.

The User requests AR app for generating underground utility information. Manage Server approves AR mode accessing and smart device executes application. On the executed Screen, a program starts to enable the user to select the type of pipe desired to be displayed in AR. A user selects a type of the pipe required to output on the screen. When the check data for AR is formed, the system identifies the current location information to search for the location information

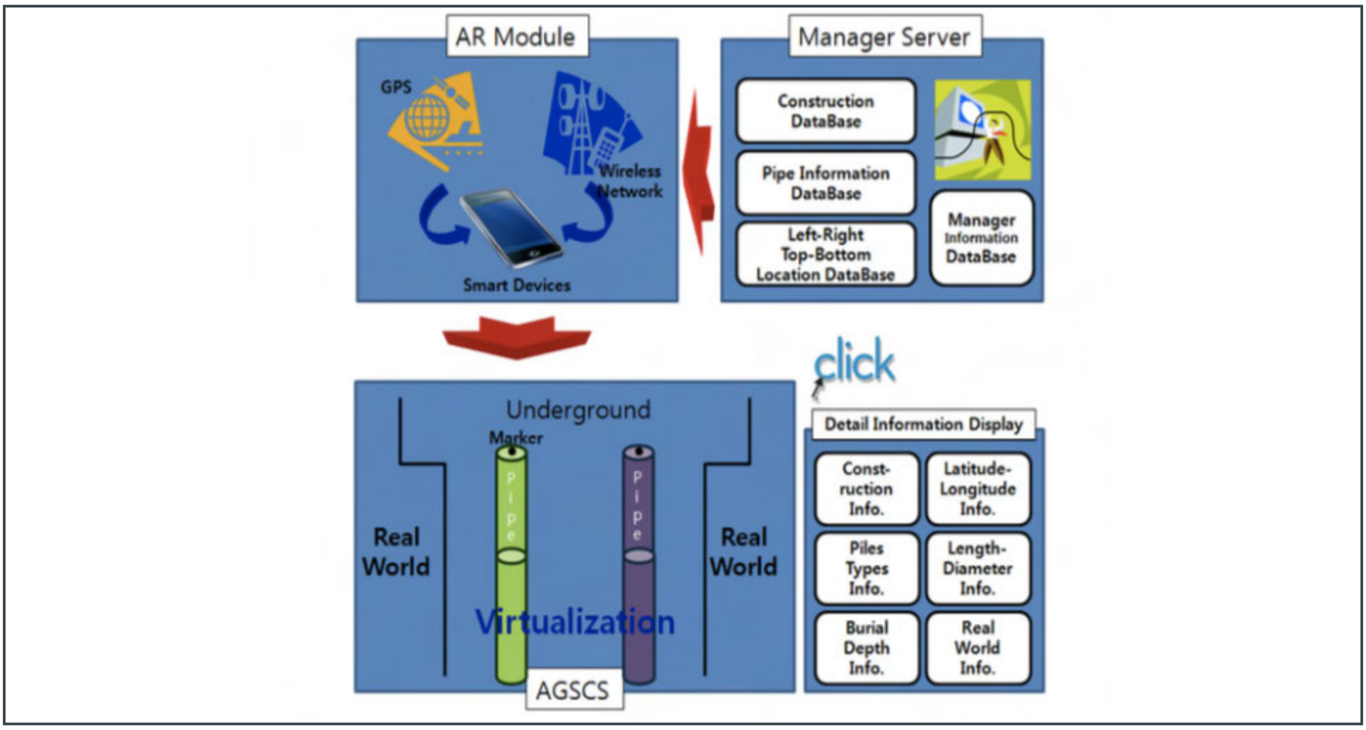

Figure 1: System Block diagram

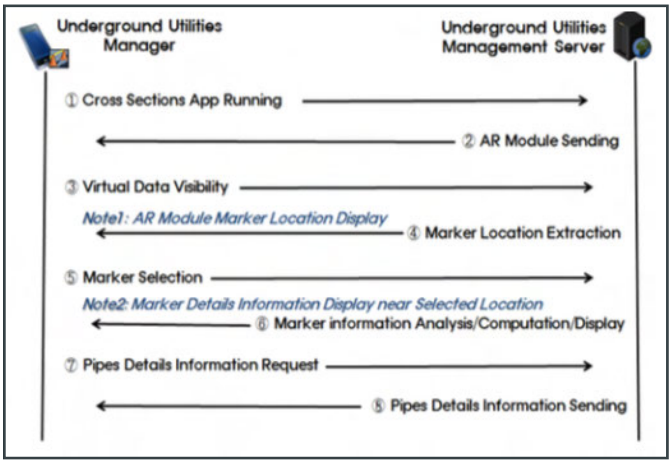

Figure 2: AR based data generation system workflow

of the user selected current information and shows the underground utilities on the screen in AR. All the utilities are shown with different color theme like water pipelines in blue, sewerage pipes in gray; gas pipeline is yellow, optical fibre cables in green and power lines in red.

While the system can produce and display AR data on the screen based on the location information of the marker by selecting the location of user's marker accurately, if the user selects a location on a road which is not the location of a marker, the system searches for the location of the closest marker on the basis of the coordinates selected and generates and displays the graphic data on the screen by analysing the location information and depth information of the selected utility at the location of the marker.

When the output data is clicked, an interface process is carried out to allow the user to check the detailed information about the utility.

Manage Server sends detailed information about the utility.

4. SIMULATION

For the simulating underground utilities information, an android based application is used as a base platform. The visualization of underground utilities are based on the combination of GPS and GIS database and they had higher location accuracy and portability. User sends the request to the server to get the specific information, system transcodes the request in form of the latitude and longitude information of the particular user location and send the visualizing data on mobile screen.

At the left side of the above image shows the typical GIS map of underground utility map. This is the base database of pipeline and its utilities. The snapshots of the right side shows the user selected request of the underground information where it clearly shows the specific detailed information of underground utility with respect to user location.

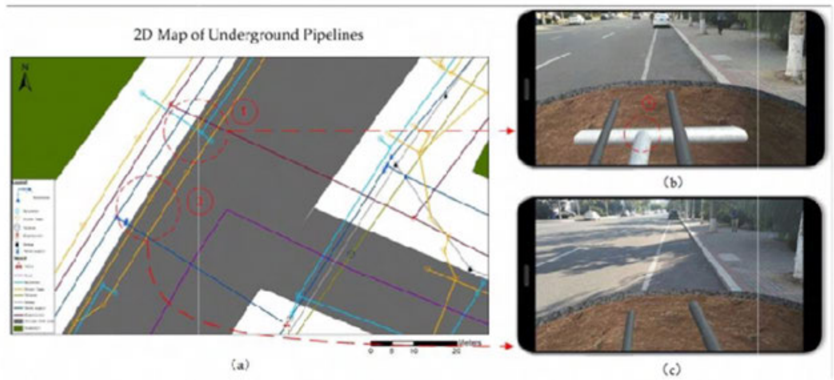

Figure: AR based 3D data simulation interface

User can get the detailed attributable information about the specific underground utility. The depth of the utility is projected with respect to the specific depth information associated with it.

5. CONCLUSION

Currently, the revolutionary technology of IT and mobility of the user are highly regarded, and IT technology makes an attempt to develop into a convergence technology with infrastructure technology. At such a point of time, studies on techniques for efficient management in underground utilities have been progressed, and the developments of utility information with IT systems which demand a convergence of underground are actively in progress. In this paper, a database is designed by analyzing special forms of underground utilities, and, on the basis of the contents designed, we designed a system which generates cross sections of utilities buried underground.

This method has enhanced sense of reality at the site by producing accurate location information for underground utilities, and by showing cross sections of underground utilities to supervisors who supervise underground utilities on the basis of the output data. We judge that this system can also act as an underground navigator which can process data in real-time being connected with underground cross sections when the user is moving on a vehicle. The method of utilizing mobile AR data for the management of underground infrastructure is not only differentiated from other existing studies but also can be a very significant study as it will enable a new efficiency of management managing response.

The proposed method guarantees through a centralized structure, and enables immediate correction of AR data and minimizes the error range by using geographical information data and short range wireless communication. Also, real-time and positive management of underground infrastructure is made possible by enabling strategic support for immediate response to irregular accidents. Later, we would like to build a whole system through actual implementation of each module based on the system presented in this paper, and to carry out additional studies to apply that built system to on-site management for a testing.

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Adapting oil & gas infrastructures to climate change

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Abstract

It is well known that natural disasters which are related to climate change (e.g. rising sea levels, heat stress, extreme precipitation, inland and coastal flooding, landslides, water scarcity etc.) are rapidly increasing through last decades. Climate impacts not only show regional and seasonal patterns, but also differ between territorial settings. As a consequence, the corresponding risk to critical infrastructures such as pipelines and their facilities is also increasing and should be carefully evaluated, while climate change may increase their cost. The severity of climate impacts on pipelines and their facilities will vary worldwide according to (a) individual locations and their geophysical risk exposure, and (b) the existing adaptive capacity and resilience. Therefore, the adaption of the pipeline project usually requires a complex, site-based analysis of different trends and impact patterns. Various norms worldwide (e. g. Directive 2014/52/EU) have foreseen to consider the vulnerability (exposure and resilience) of certain projects to major accidents and/or disasters during the Environmental Impact Assessment Procedure. This will likely lead to changes in design standards for the construction and operation of oil and gas pipelines; compressor stations etc. in order to avoid significant adverse effects on the environment.

In addition, climate change may influence the integrity and reliability of existing pipelines and associated infrastructure (upstream and downstream sections) that operate in diverse and often extreme climatic conditions; from hot deserts to permafrost areas. The climatic conditions of these areas have rapidly changed during the last decades, requesting an urgent assessment of the existing infrastructures.
The scope of this paper is to present the interrelation between pipeline projects and climate change, to present the increasing hazards and risks to existing or future infrastructure but also to highlight the incompleteness of specific methodologies that are widely used in pipeline design.

INTORDUCTION

According to the EU policy, Europe needs to be better prepared to the risk assessment and management of European Critical Infrastructures (Directive 2008/114/EC) by upgrading or construct critical infrastructures that are resilient to natural, man-originated hazards and to climate change. According to Directive 2011/92/EU development consent for public and private projects which are likely to have significant effects on the environment should be granted only after an assessment of the likely significant environmental effects of those projects has been carried out.

The Directive 2014/52/EU refers that in the case of critical infrastructures a process entitled "environmental impact assessment" should be performed and during this the following steps should be followed:

i. preparation of an environmental impact assessment report by the developer,
ii. carrying out of consultations with the authorities,
iii. examination by the competent authority of the information presented in the environmental impact assessment report and any supplementary information provided, where necessary, by the developer,
iv. reasoned conclusion by the competent authority on the significant effects of the project on the environment, and,
v. integration of the competent authority's reasoned conclusion.

This Directive also refers that the environmental impact assessment shall identify, describe and assess in an appropriate manner, in the light of each individual case, the direct and indirect significant effects of a project on the following factors:

a) Population and human health;
b) Biodiversity, with particular attention to species and habitats protected under Directive 92/43/EEC and Directive 2009/147/EC;
c) Land, soil, water, air and climate;
d) Material assets, cultural heritage and the landscape;
e) The interaction between the abovementioned factors.

Among others the environmental impact assessment study should include the following issues:

a) a description of the likely significant effects of the project on the environment;
b) a description of the features of the project and/or measures envisaged in order to avoid, prevent or reduce and, if possible, offset likely significant adverse effects on the environment;
c) a description of the reasonable alternatives studied by the developer, which are relevant to the project and its specific characteristics, and an indication of the main reasons for the option chosen, taking into account the effects of the project on the environment

The oil and gas industry used to and is still playing a very important role in the global energy sector, while the upstream, midstream and downstream processes have significant impact on all the productive sectors of the economy, on the population and on environment. In nowadays, crude oil and oil products have the biggest portion in gross inland energy consumption, while gas, either natural or liquefied is one of the main energy sources for electricity generation and for thermal power. The need for this consumption led and undoubtedly will lead to the construction of very significant energy infrastructure projects worldwide, (e.g. pipelines, tanks, refineries, offshore platforms etc.) during this and the previous century, that should be comply with the above- mentioned European Directives or similar originated from other countries. Note that projects were constructed before the publication of these Directives might not be complying with the above mentioned Directives. Climate change is a complex phenomenon which is expected to bring in the years to come, warmer temperatures, rise in sea levels, ice melting in the Arctic, wild forest and bushfires, more frequent and severe extreme weather events, such as very heavy rainstorms, flooding, tornadoes, drought, high sea waves, etc. and decreased availability of natural resources such as fresh water. The impacts includ-

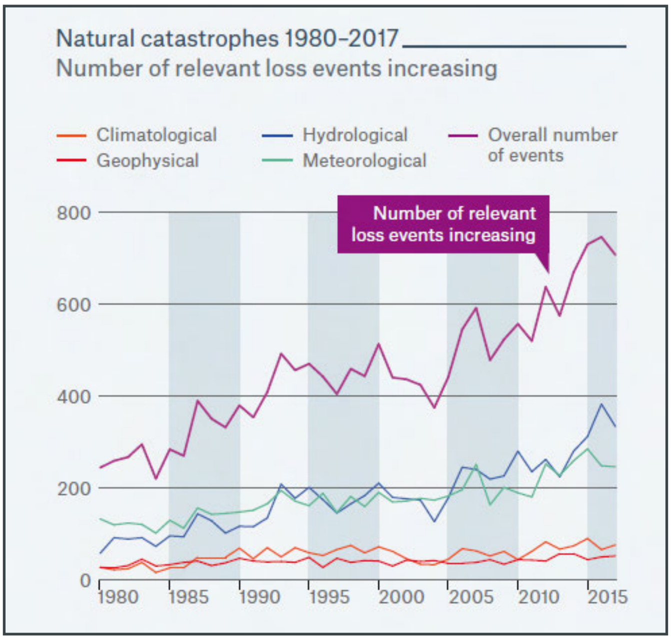

Figure 1: Overall losses due to geophysical (earthquakes and volcanic activity), meteorological (storms, tropical storms etc.), hydrological (flood and mass movement) and climatological (high temperature, drought, wildfires) events. (Source: Munich RE, 2018)

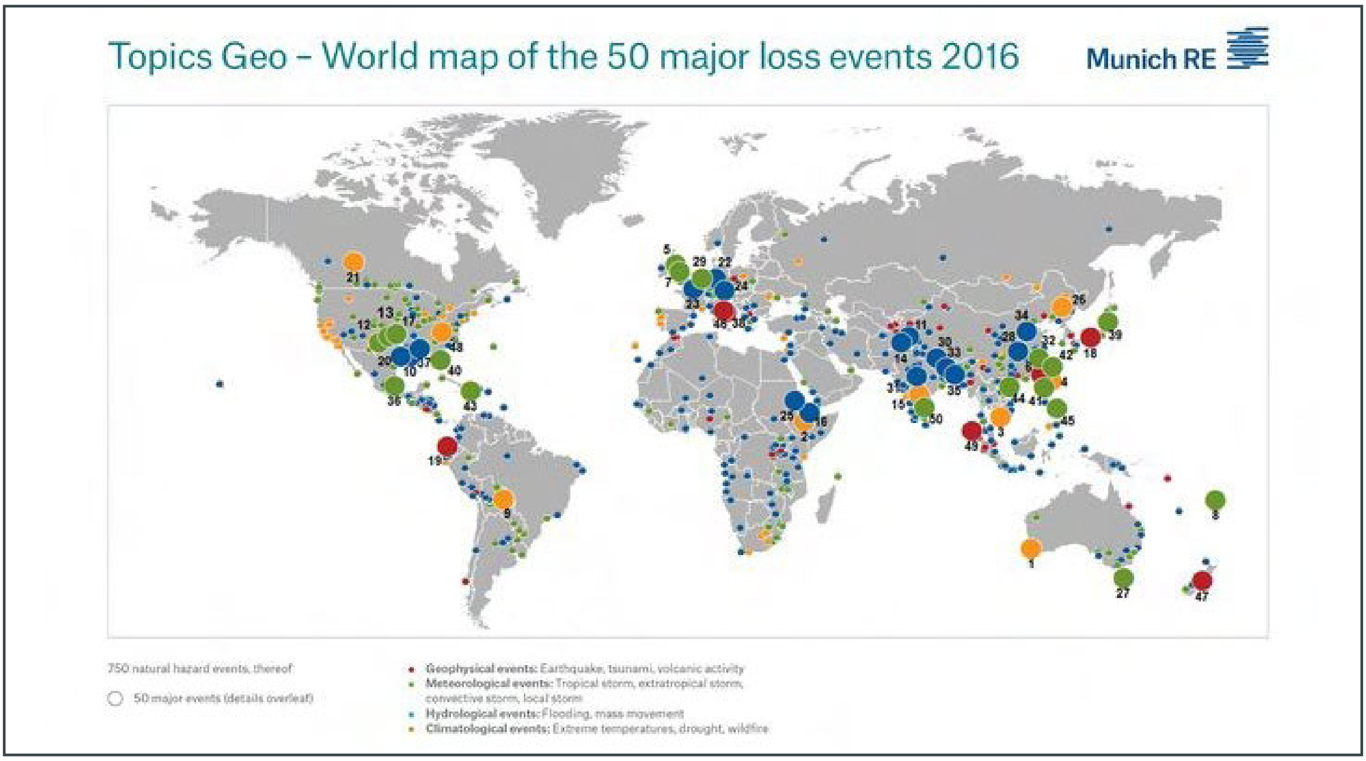

Figure 2: World map of the 50 major loss events of 2016 due to geophysical (earthquakes and volcanic activity), meteorological (storms, tropical storms etc.), hydrological (flood and mass movement) and climatological (high temperature, drought, wildfires) events. (Source: Munich RE, 2017)

ing economic cost of these events are expected to increase in significance and phenomena that were characterised as historically rare will become more common and intense due to climate change (Figure 1, Munich Re, 2018, Figure 2, Munich Re, 2017). This figure illustrates the significant increase in hydrological and meteorological events from 1980 to 2017 and the slightly increase in climatological events. The same long-term trend followed in 2018, where 850 events were registered; geophysical events such as earthquakes, tsunamis and volcanic eruptions accounted for 5% of the total, while storms made up 42%, floods, flash floods and landslides 46%, and finally 7% fell into the categories of heat, cold and wildfire (Löw, 2019).

A very well-known example from climatic change and its impact to oil and gas industry is the hurricanes Katrina and Rita, which caused extensive damage to the regional natural gas and oil infrastructures, destroying more than 100 platforms, damaging 558 pipelines, and shutting down nine refineries, effectively halting nearly all oil and gas production for almost six months and cutting US annual oil production by over 20% (Smith, 2013, GAO, 2014). The heat waves in Europe in 2003, 2010 and 2019 demonstrated the effects of extreme events by causing thousands of fatalities, decreasing power production, and temporary shutdown of water-cooled nuclear power plants.
Thus, the scope of this paper is to propose a specific methodology aiming to adapt the new and already existing oil and gas projects to hazards derived from climatic change.

This methodology should:

a) primary identify the exposure of the oil and gas industry to climate change
b) assess the oil and gas infrastructure's vulnerability, and,
c) calculate the ensuing risk and propose measures and actions that should be taken for the oil and gas infrastructures

2. PROPOSED METHODOLOGY

2.1 CLIMATIC HAZARDS

Global atmospheric emissions of carbon dioxide (CO_2) and other polluting gases have increased markedly over the last 200 years which has contributed to a faster warming of the earth's climate. Climate change could pose significant risk to energy infrastructure while its effects are already under way and are projected to continue. Extreme weather periods, such as heat waves and droughts could lead to demand-driven overstress of energy infrastructure especially offshore and coastal, thus threatening national energy security. Floods appear to be occurring more frequently, while in near future this trend is expected to be increased. Warmer winter will lead to early snowmelt or even to absence of snow while at the same time rainfalls will be increased. The increment of rainfalls will potentially increase the number or landslides. Higher temperatures and drought will increase the frequency and magnitude of forest fires. Strong winds, hurricanes and tornadoes at an offshore environment will create high sea waves that could (a) affect the seabed at very shallow waters, (b) create erosion at the coastal line. Table 1 summarizes those hazards and their consequence to climate. Those hazards can appear alone and could react on local level affecting small geographical areas or can occur simultaneously affecting entire countries or part of entire continent.

According to US Department of Energy (2010), some climate change impacts are likely to interact with others, creating a compounding effect. For example:

- Higher air and water temperatures may contribute to both an increase in electricity demand and a decrease in electricity supply.
- The effects of sea level rise may be aggravated by more severe storms and coastal erosion, causing flooding across a larger area. Storms can also damage natural features, such as wetlands, and manmade structures, such as sea walls, that help protect coastal infrastructure from sea level rise and storm surges.
- Higher temperatures and drought could limit the amount of electricity that can be generated and transmitted during times of peak demand.

2.3 VULNERABILITY OF CLIMATIC HAZARDS TO OIL AND GAS INDYSTRY

Figure 3 presents the supply sequence in the oil and gas industry. Upstream section involves the onshore and offshore extraction and is the most complex of the oil and gas segments, midstream section encompasses transportation, processing, storage and distribution operations and finally

Table 1: Climatic hazards

Climate hazards	Consequence to environment
High temperatures	Bushfires, thawing, decrease of fresh water
Drought	Bushfires, decrease of fresh water
Low temperatures	Increased permafrost
Strong winds	Drought, high sea waves, sand transfer from deserts
Heavy rainfall/snowfall	Flood, landslides, snow avalanches
Storms/Hurricanes/Tornadoes	Flood, lighting strikes and high sea waves
Sea level rise	Floods, coastal erosion, coastal landslides

Table 1: Climatic hazards

downstream section contains the Refining and Processing of Natural Gas and Liquid Natural Gas. In consequence, the assets of this industry are the following: drilling ships, jack-ups, platforms, oil wells, etc. at the offshore technology, drillings rigs, oil and/or gas wells, oil pumping stations, etc. at the onshore technology, onshore/offshore oil and gas pipelines, tankers, vessels, ports, marine terminals, trucks, rail trucks, coastal or onshore refineries, onshore, near-shore or offshore refined products storage tanks, facilities and offices buildings and last but not least people.

The vulnerability of oil and gas facilities from climate change can be categorized as follows:

- Operational loss of an infrastructure (i.e. impact on one or more of the main processes of the infrastructure,
- Severe to very severe to completely damage of the infrastructure,
- Cascading effects from losses or damages of other critical infrastructures of the same or other energy sector (e.g. electricity),
- Fluctuations on demand and on consumption from the society in local or national level.

Taking into consideration the data presented at Figure 1, as well as numerous studies published worldwide, it is evident

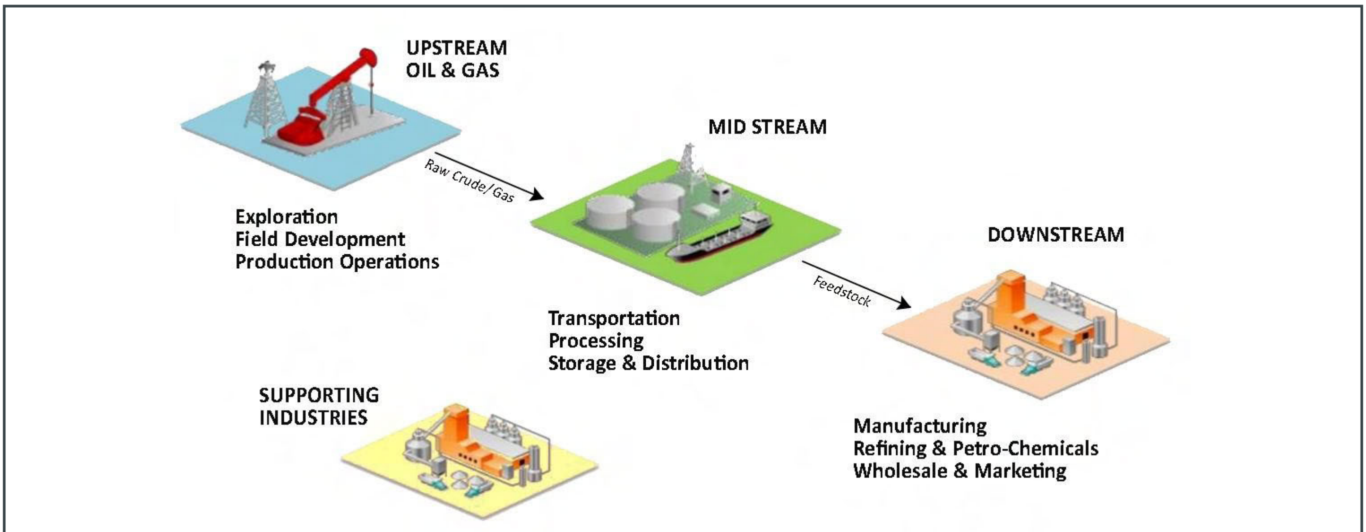

Figure 3: Supply sequence in oil and gas industry (Source: https://avata.com/oil-and-gas)

that oil and gas industry is mainly exposed to hydrological and meteorological data, thus the next table (Table 2) presents the potential climate change impacts on oil and gas infrastructure. Note that Table 2 does not present cascading effects which means that damages or loss of a major component of a critical infrastructure could severely affect another critical infrastructure of the same energy sector or other energy sector.

Supply sequence	Climate hazard	Vulnerability
Upstream	High temperatures	Thawing may cause instability to onshore platforms or wells
		The movement of a detached iceberg may affect the operation of offshore platforms
		The reduction of fresh water might reduce the operation time of drilling machines
		Bushfires may affect the operational time. Poor air quality.
		Impact on cooling units, need for increased air conditioning in plants' buildings, operational reduction in plants' units which are using electrical power.
		Workers are exposed during their shift to extreme heat (for a specific period of the day) or for days
	Drought	The reduction of fresh water might reduce the operation time of drilling machines
		Bushfires may affect the operational time
	Low temperatures	Difficulties for circulation of fresh water
		Workers are exposed during their shift to extreme cold (for a specific period of the day) or for days
	Strong winds	The operation might stop during strong winds (both in onshore and offshore environment). Mainly platforms expected to be affected.
		Workers are exposed during their shift. They should avoid working at height.
	Heavy rainfall/snowfall	Onshore and coastal facilities expected to be affected due to flooding
		Landslides or even snow avalanches might affect extraction sites or transportation networks.
	Storms/Hurricanes/Tornadoes	The operation might stop during strong winds (both in onshore and offshore environment). Mainly platforms expected to be affected.
		Lightning strikes may affect onshore and offshore platforms. Offshore platforms might become isolated
		Workers are exposed during their shift
	Sea level rise	Coastal facilities expected to be affected due to flooding
Midstream	High temperatures	Increased need for electrical power might decrease the operation of process units or coolant networks.
		The decrement of oil or gas flow from upstream may lead to the decrement or interruption of the process units
		Transportation of liquid by trucks or rail trucks could be delayed
		Workers are exposed during their shift to extreme heat (for a specific period of the day) or for days
	Drought	Might lead to faster ageing of tanks or pipelines above ground
		Might impact the process due to reduced amount

Midstream		of fresh water
	Low temperatures	Freezing of coolant networks
		Might lead to faster ageing of tanks or pipelines above ground
		Transportation of liquid by trucks or rail trucks could be delayed
		Workers are exposed during their shift to extreme cold (for a specific period of the day) or for days
	Strong winds	Transportation of liquids through sea may be delay due to high sea waves. Accident is very probable.
		Probable damages to transmission lines
		Empty tanks, light-structure buildings might be affected
		Workers are exposed during their shift. They should avoid working at height.
	Heavy rainfall/snowfall	Onshore and coastal facilities expected to be affected due to flooding. Problems with foundation facilities (erosion, differential settlements, tilting etc). Various facilities – if empty – might face the buoyancy effect.
		Landslides or even snow avalanches might affect plant sites or transportation networks. Soil erosion phenomena are probable.
		Transportation of liquid by trucks or rail trucks could be delayed
		Sites might be inaccessible during the phenomena. Bridges may collapse. River, streams, gullies could be eroded and affect buried pipelines.
	Storms/Hurricanes/Tornadoes	Lightning strikes may affect compressor stations, above ground pipelines, refining buildings, etc.
		Transportation of liquid by trucks or rail trucks could be delayed
		Probable damages to transmission lines
		Transportation of liquids through sea may be delay due to high sea waves. Accident is very probable.
		Collapse of flood protection systems leading to refineries flooding
		Damagers to plants buildings. Removal of roofs, and other structural damages
		Workers are exposed during their shift
	Sea level rise	Coastal facilities expected to be affected due to flooding. Transmission lines could be found under seawater – need for re-alignment.
Downstream	High temperatures	Increased need for electrical power might decrease the operation of refining process units or coolant networks.
		High temperatures may lead to thermal discomfort
		Workers are exposed during their shift to extreme heat (for a specific period of the day) or for days
	Drought	Might lead to faster ageing of facilities
		Might impact the refining process due to reduced amount of fresh water
	Low temperatures	Freezing of coolant networks

		Might lead to faster ageing of facilities
		Workers are exposed during their shift to extreme cold (for a specific period of the day) or for days
	Strong winds	Transportation of liquids through sea may be delay due to high sea waves. Accident is very probable.
		Probable damages to transmission lines
		Light-structure buildings might be affected
		Workers are exposed during their shift. They should avoid working at height.
	Heavy rainfall/snowfall	Onshore and coastal facilities expected to be affected due to flooding. Problems with foundation facilities (erosion, differential settlements, tilting etc.). Various facilities might face the buoyancy effect (e.g. buried pipelines).
		Landslides or even snow avalanches might affect sites. Soil erosion phenomena are probable.
		Transportation of liquid by trucks or rail trucks could be delayed
		Sites might be inaccessible during the phenomena. Bridges may collapse. River, streams, gullies could be eroded and affect buried pipelines.
	Storms/Hurricanes/Tornadoes	Lightning strikes may affect above ground pipelines, refining buildings, etc.
		Transportation of liquid by trucks or rail trucks could be delayed
		Probable damages to transmission lines
		Transportation of liquids through sea may be delay due to high sea waves. Accident is very probable.
		Collapse of flood protection systems leading to refineries flooding
		Damagers to plants buildings. Removal of roofs, and other structural damages
		Workers are exposed during their shift
	Sea level rise	Coastal facilities expected to be affected due to flooding. Transmission lines could be found under seawater – need for re-alignment.

Table 2: Impact of climatic hazards to oil and gas infrastructures

2.4 PROPOSED MEASURES, ACTIONS AND FURTHER DISCUSSION

Almost thirty years ago the oil and gas industry started to pay attention to the reduction of greenhouses gas emissions and those primary plans did not take into consideration adaptation actions and plans for the upcoming climate change.It is rather evident that climate change will finally lead to the enhancement of oil and gas industry's assets against climate hazard. This technological improvement will be based on the assets' adaptation to the climatic characteristics and changes of local (national) level, rather than climatic simulation models of urban scale. Since climate change will also influence the integrity and reliability of existing oil and gas infrastructures, it is expected that changes in design standards for the operation of oil and gas infrastructures will occur. Table 3 presents adaptation actions that should be taken into consideration against climate change.
The Paris agreement (2015) introduced the implementation of adaptation measures to national strategies between member states. The adaptation policy should refer to a detailed program of activities at a national level aiming to address the consequence of climate change. The steps that should be followed in national level are presenting hereinafter, and to Figure 4.

Step 1: Estimation and monitoring of climate hazards and assess of their risk.
Step 2: Calculation of the assets' fragility and vulnerability over these hazards and calculation of their risk.
Step 3: Development of the public or private organization's strategy for the assets or infrastructures adapted to climate change.
Step 4: Development of the public or private organization's governance around climate change.

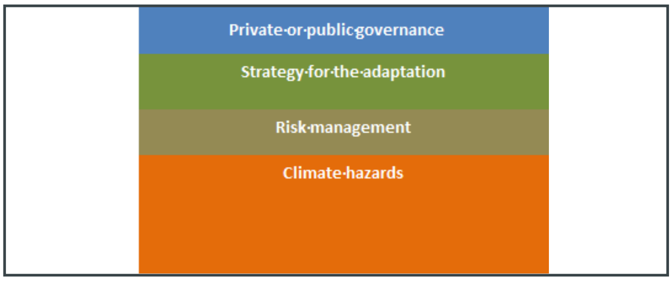

Figure 4: Activities at national level for the adaptation from the consequences of climate change

Supply sequence	Climate hazard	Adaptation measures
Upstream	High temperatures/Drought	Clean water supply derived from water sewage treatment plant or water desalination for: • Hydraulic fracturing • Fire extinguishing • Cooling units • Personnel
	Low temperatures	Clean water supply derived from water sewage treatment plant or water desalination for • Heating units • Preventing frost
	Storms/Hurricanes/Tornadoes/Strong winds	Upgrade the foundation and structural elements of the infrastructure's asset (e.g. need for better anchoring in offshore platforms). Revise norms by incorporating the threshold for wind speed, height of waves, frequency of lightning strikes, etc. Develop of automatic alarm systems. Potential need for higher decks at offshore platforms. Potential need for construction of new pipelines. Revise health and safety norms and policies for personnel; execute training exercises for evacuation under these unfavorable weather conditions.
	Heavy rainfall/snowfall	Revise norms against flooding. Build high concrete walls and dykes. Develop of automatic alarm systems. Locate and monitoring areas that will be affected by potential landslides or even snow avalanches.
	Sea level rise	Revise norms against flooding. Build sea walls. Calculate buoyancy effects. Might need to place in higher altitudes critical components of assets. Waterproofing of equipment.
Midstream	High temperatures// Drought	Clean water supply derived from water sewage treatment plant or water desalination for: • Fire extinguishing • Cooling units • Personnel Upgrade the structural elements of the infrastructure's asset
	Low temperatures	Clean water supply derived from water sewage treatment plant or water desalination for • Heating units • Preventing frost Revise health and safety norms and policies for personnel. Need to construct new pipelines for transportation instead of using trucks or rail trucks
	Storms/Hurricanes/Tornadoes/Strong winds	Upgrade the foundation and structural elements of the infrastructure's asset
		Need to construct new pipelines for transportation

Midstream		instead of using vessels or tankers.
		Revise norms against strong winds. Develop automatic alarm systems.
		Revise health and safety norms and policies for personnel.
	Heavy rainfall/snowfall	Revise norms against flooding. Build high concrete walls and dykes
		Locate and monitoring areas along long infrastructures that will be affected by potential landslides or even snow avalanches. Apply mitigation measures also for soil erosion. Develop of automatic alarm systems. Some facilities might be affected by buoyancy. Waterproofing of equipment.
		Revise health and safety norms and policies for personnel.
	Sea level rise	Revise norms against flooding. Build high concrete seawalls and dykes.
Downstream	High temperatures/Drought	Clean water supply derived from water sewage treatment plant or water desalination for: • Fire extinguishing • Cooling units • Personnel Upgrade the structural elements of the infrastructure's asset
	Low temperatures	Clean water supply derived from water sewage treatment plant or water desalination for • Heating units • Preventing frost Revise health and safety norms and policies for personnel.
	Storms/Hurricanes/Tornadoes/Strong winds	Upgrade the foundation and structural elements of the infrastructure's asset. Potential need for the construction of sea walls, concrete walls, dykes etc. Revise norms by incorporating the threshold for wind speed, height of waves, frequency of lightning strikes, etc. Might need new transportation means (e.g. pipelines). Relocation and safe placement of the crucial components of infrastructures Revise norms against flooding. Develop of automatic alarm systems Revise health and safety norms and policies for personnel; execute training exercises for evacuation under these unfavorable weather conditions.
	Heavy rainfall/snowfall	Locate and monitoring areas that will be affected by potential landslides or even snow avalanches. Apply mitigation measures also for soil erosion. Some facilities might be affected by buoyancy.
	Sea level rise	Revise norms against flooding. Build sea walls. Waterproofing of equipment. Calculate buoyancy effects. Might need to place in higher altitudes critical components of assets

Table 3: Impact of climatic hazards to oil and gas infrastructures

The final scope of the above presented actions will be the establishment of climate resilient assets and infrastructures of the oil and gas industry. These components should resist to future climate over their lifetime (induse2safety, 2017).

It should be mentioned that EU is working on climate change adaptation policies and actions mainly through European Commission's science and knowledge service; the Joint Research Centre (JRC). For floods, JRC developed the European Flood Awareness System where high-resolution regional climate information, pan-European hydro-morphological datasets are used, while hydrological modelling techniques and statistical analyses were being performed. For droughts JRC developed the European Drought Observatory, to monitor, assess and forecast droughts and their impacts on society and the environment of Europe, Africa and Latin America. Finally for forest fires the European Forest Fire Information System was developed where large fire events over the past 20-30 years were mapped and analyzed. Since climate change will affect the oil and gas infrastructures, the appearance of a Natech event will be increased. In Europe, the "Seveso III" Directive 2012/18/EU, which presents rules for the prevention of major accidents that might result from certain industrial activities and the limitation of their consequences for human health and the environment, requires specifically the assessment of Natech risks.

Additionally combined threats from natural disasters due to climate change, terrorist attacks and cyber-attacks will become in the near future one of the major concerns for the oil and gas industry. Thus, infrastructures that will be more resilient to those phenomena should be constructed. And finally, oil and gas companies mainly inside EU and States will continue to experience increased political pressure for emissions accountability and expansion of the contribution of renewable energy to their energy supply portfolios (Finley and Schuchard, 2009).

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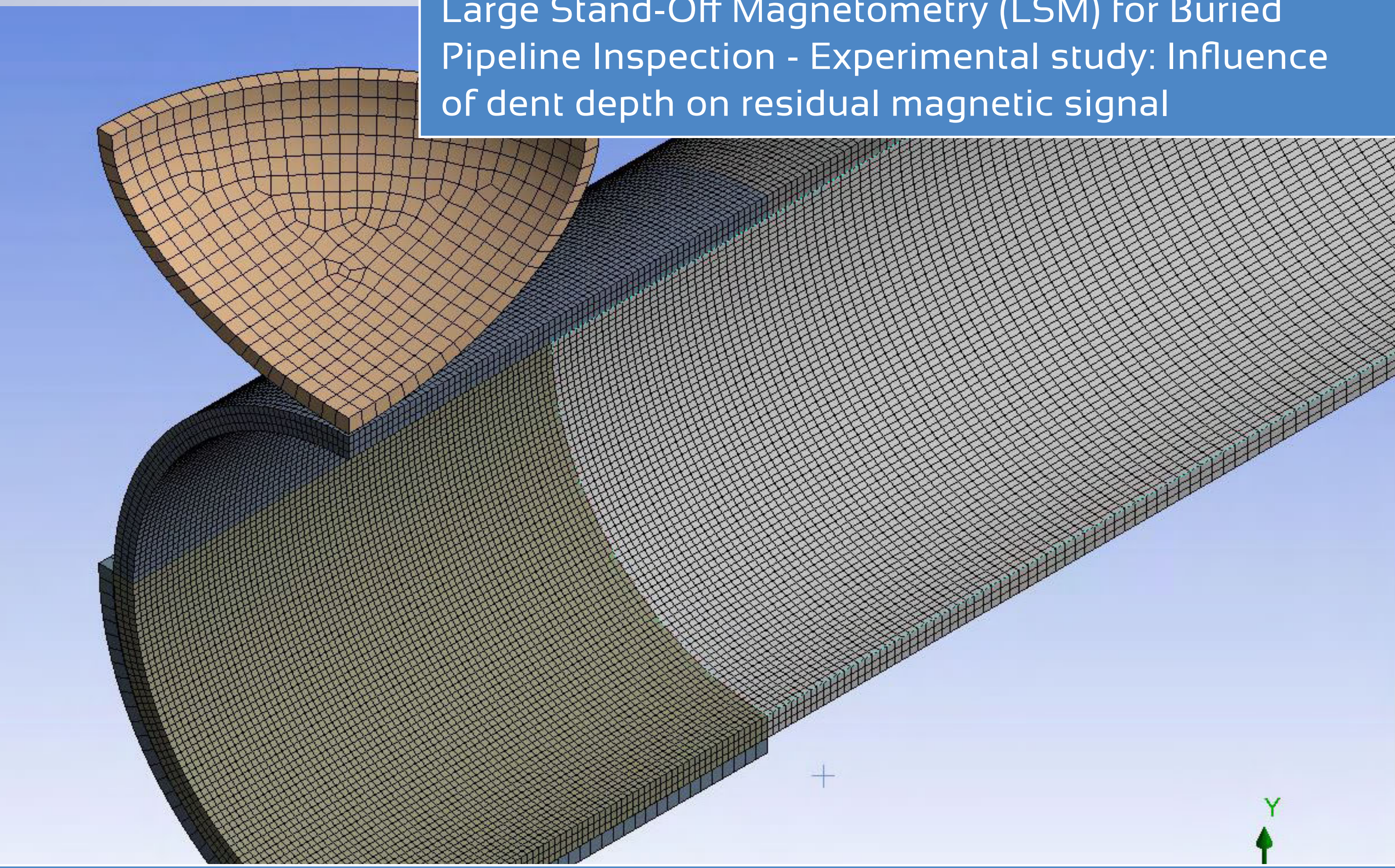
Large Stand-Off Magnetometry (LSM) for Buried Pipeline Inspection - Experimental study: Influence of dent depth on residual magnetic signal



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> Skipper NDT; Institut de Physique du Globe de Strasbourg; TOTAL E&P; Cetim

Abstract

Dents are among the anomalies which may be a threat to safe operation of pipelines. Dents are characterized by plastic deformation, which causes changes in the magnetic properties of the ferromagnetic pipe wall. Skipper NDT, a company at the forefront of LSM technology, conducted trials to characterize changes in magnetic properties around dents. The objective of the study was to improve the value of the results of the LSM inspections carried out for pipeline operators. Dents with a depth of 5%, 10%, and 15% were indented on X42 pipes of 150 mm (6 inches) diameter, 7 mm wall thickness and 12 m length. Multiple gauges were located around the area of the dents to measure strain during indenting. Mechanical behavior was simulated using the Ansys finite element software to assess accurately the stress distribution around the impacted area and confirm the data recorded using the gauges. Before and after making the dents, magnetic properties were measured using high resolution three-components fluxgate magnetometers at several heights above the pipes on a proprietary test bench developed by Skipper NDT. This paper describes the experimental trials and the results in terms of magneto-mechanical behavior. It is concluded that LSM technology can be used to improve the detection and characterization of dents on pipelines.

1 .INTRODUCTION

Pipelines are the most effective means of transporting large volumes of oil & gas products. The safe, environmentally responsible operations are always the priority of pipeline operators. To achieve this goal, pipeline operators inspect their pipelines periodically to identify and evaluate any anomalies in the pipe wall. A novel way to perform these inspections, without contact and thus causing no operational impact, is based on LSM technology. These inspections are run in-line and above-ground. LSM technology is based on established physical principles, namely the Villari effect [1] or the Inverse Magnetostrictive Effect. This principle states that any anomaly generating stress in a ferromagnetic pipe wall generates a change of magnetic induction. Therefore, accurate magnetic measurements above ground along the pipeline combined with advanced signal processing tools enables the detection of anomalies that generate stress in the pipe wall. For several years, research has been dedicated to solving the complex problem of establishing a fundamental relationship that governs magneto-mechanical coupling [1]–[4].

Skipper NDT offers inspection services using the LSM technology and has been conducting a joint research program with TOTAL for more than 2 years to improve the probability of detection of anomalies on steel pipelines. Skipper NDT has developed a significant expertise in this area through laboratory tests, rigorous research, simulation work and real measurements on buried pipeline networks. Because dents are among the anomalies affecting pipeline integrity, they are of concern to operators. This type of anomaly is characterized by plastic deformation and strong variation of mechanical stress around the defect [5]–[10].

In the present study, we introduce the first part of the work, conducted on plain smooth dents at the CETIM laboratory in France (Centre des Etudes Techniques des Industries Mécaniques), and report the preliminary results. This work aims to:

- assess the ability to detect dents
- define a relationship between the measured magnetic signal and the type and depth of dent
- To perform this experimental work, three procedures were implemented:
- design and construction of a non-magnetic measurement bench
- mechanical modeling by finite element software
- making plain smooth indentations in the middle of 3 pipe joints

These procedures will be discussed in this paper. The magnetic results obtained will be presented with a detailed analysis, in addition to Skipper NDT's perspective to improve the detection of dents.

2. THE NON-MAGNETIC TEST BENCH

A wooden test bench was designed and built in order to acquire high-resolution magnetic signals from tubular or pipe structures. The bench is composed of a base which supports the pipe to be measured and a tower supporting the magnetic acquisition hardware. The tower is then towed over the 16-metre length of the base to acquire the tube's magnetic signal from beginning to end. The entire

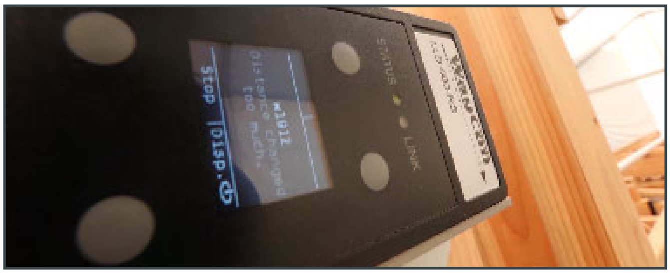

Figure 1: Non-Magnetic test bench - Skipper NDT's proprietary bench, 3 out of 9 sensors & a laser distance meter

bench structure was built with materials free of magnetic interference (no metal). Several parameters can be tested, such as:

- Standoff: the distance between the magnetic sensors and the upper surface of the pipe can vary from 250 mm to 2,500 mm with 50 mm intervals
- Position of the defect: the pipe can be rotated around its axis to measure the defect in different axial positions
- Size of the pipe: the bench can host pipes up to 14-metres long with diameters ranging from 100 to 500 mm (4 to 20 inches).

The tower mounted on the bench houses a purpose-built magnetic recording device that has a resolution higher than 1 nT with an acquisition frequency of up to 2,000 Hz. The following combination of instruments was assembled in order to provide the necessary measurement precision:

- 9 high-precision three-components fluxgate magnetometers, the configuration of which can be changed if needed (Figure 1b), 25 cm horizontal spacing.
- 2 lasers distance meters (vertical and horizontal): one to read the distance from the end of the pipe and the other to measure the exact height relative to the upper surface of the pipe. This allows for high spatial resolution of the data acquired (Figure 1c),
- A datalogger to record and synchronize the data.

3. PREPARATION OF PLAIN SMOOTH DENTS IN PIPES

Indenting the pipe was entrusted by Skipper NDT to the CETIM team, specialized in the mechanical field.

Plain smooth dents were chosen to avoid any magnetic effect (such as thickness reduction in curvature) other than the effects of deformation and stress. Seamless joints were chosen to avoid any magnetic effect of welding. Three depths of dents were selected: 5%, 10% and 15% of the outside diameter.

1. Experimental joints

   The mass and size of joints to be handled in the laboratory were limited, so the characteristics of the 3 joints were
   - diameter: 168.3 mm,
   - wall thickness: 7 mm,
   - grade: X42 (API 5L),
   - length: 10 m,
   - seamless.

   A tensile test according to the standard NF EN 2002-001 (2006) was performed on a sample taken from the end of each joint (identified 20, 21 and 22) to measure the actual mechanical properties, such as the elastic limit and the Young's modulus.

2. Preliminary mechanical simulation

   For control of the mechanical test, it was imperative to begin a simulation study. This modeling allowed control of certain parameters, such as:

   - the level of stress to be applied to achieve the 5, 10 and 15 % dent depth,
   - placement of each strain gauge in areas where the mechanical stress does not exceed its limit so as not to degrade it,

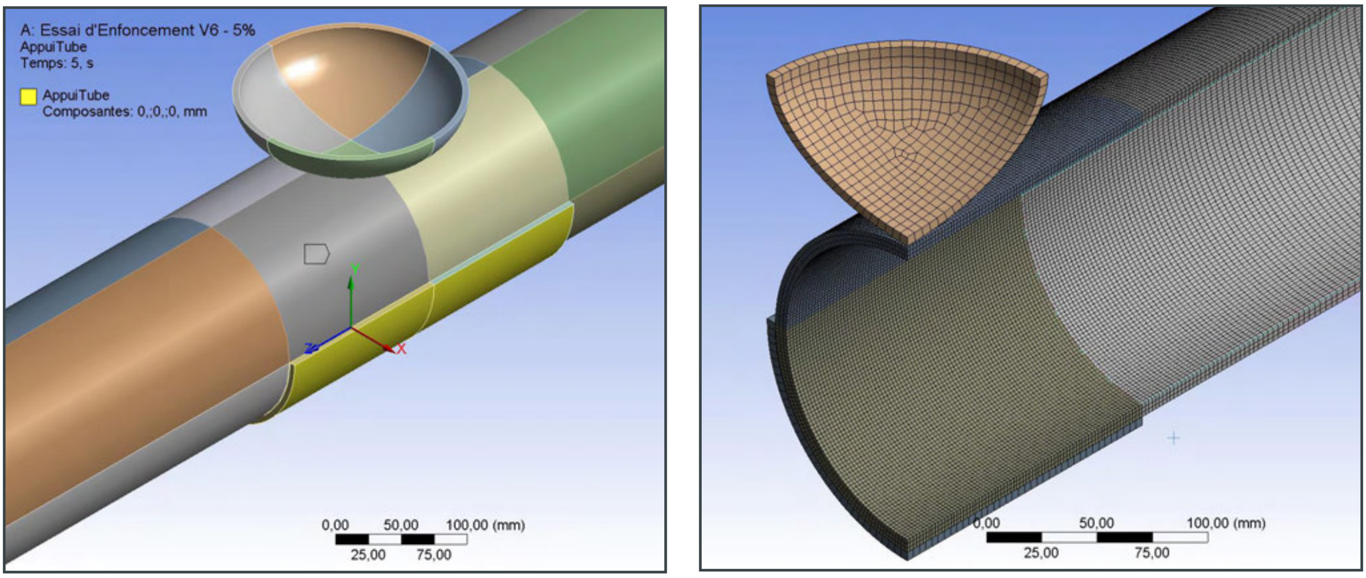

Figure 2: Mechanical Simulation

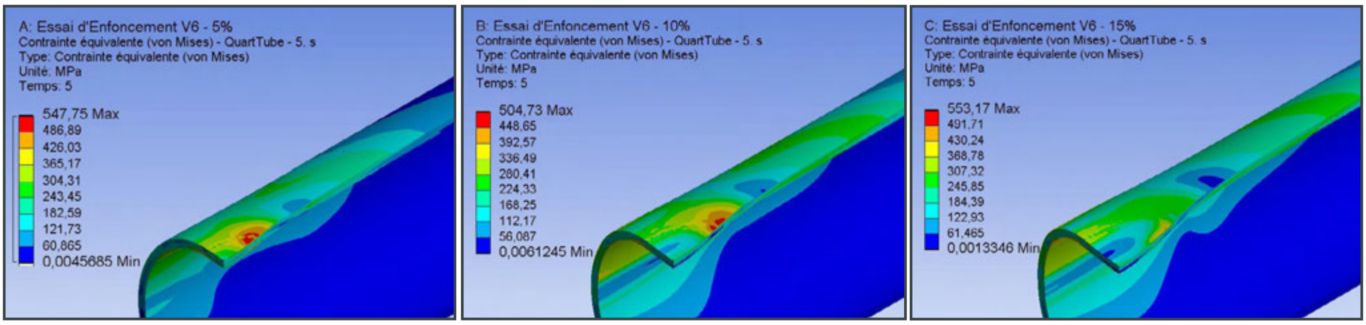

Figure 3: Von Mises equivalent stress a. 5% b. 10% c.15%

- the distribution (on the surface and in the through-wall direction) of stress in each dent.

The CETIM team used the Ansys software for mechanical modeling (Figure 2-3). The indenter was modeled in an ellipsoidal shape with half-axes of 90 mm and 50 mm. To avoid excessive bending of the pipe due to its own weight, it was supported by six planks, placed at intervals of about 2,000 mm (Figure 4). The stress-strain curves obtained in the tensile tests were used for mechanical simulation.

The depression of the tube by the indenter was realized by applying a vertical displacement imposed on the inner face of the indenter (Figure 2). Three displacement values were applied, -9 mm, -17.4 mm and -25.7 mm, in order to generate dent depths of 5%, 10 % and 15%, respectively, of the outer diameter of the tube.
In Figure 3, the equivalent mechanical stress of Von Mises is represented. These plots show the enlargement of the plastic zone (σ> 320 MPa) with increasing depth of the dent. Stress does not increase linearly with the depth of dent, but a complex distribution of stress is generated within the impact section. It will be difficult to define a direct relationship between a single stress value and the magnetic field that is measured. The field induced by the material is the result of stress distribution in a section.

3. Dent: mechanical experiment
A flexion bench has been specially designed for these tests. The bench contains a joint support which makes it possible to limit the friction and the sliding of the joint under the effect of the press. The force applied to the joint is generated by a hydraulic jack.
Three triaxial gauges were placed near the impact zone of the indenter. During the test, the indenter displacement and the different components of the 3 gauges (Ra, Rb and Rc) were recorded (Figure 5).

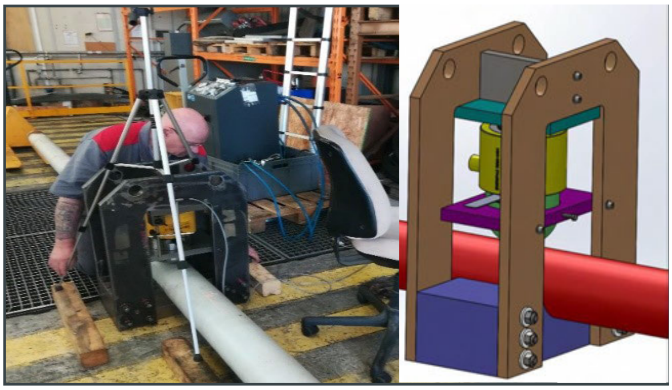

Figure 4: Mechanical flexion bench

In Table 1, the maximum values of strain measured by the 2 gauges (R1, R2) located on the upper surface of the joints and the values obtained by simulation on the same section for each level of depth are listed.

The gauge R3 is positioned on the section which undergoes ovality during the test. In this section, there is a sudden variation of the stress during the test on the three tubes.

For this reason, the measurements of this gauge are not considered. Measurements of the two gauges R1

	5%		10%		15%	
	Sim	Exp	Sim	Exp	Sim	Exp
R1	1.47 %	1.5 %	1.50 %	1.53 %	1.51 %	1.6 %
R2	2.51%	2.2 %	2.47 %	2.3 %	2.54 %	2.25 %

Table 1: Max values of strain ε (%) measured values (gauge measurements) / simulated values

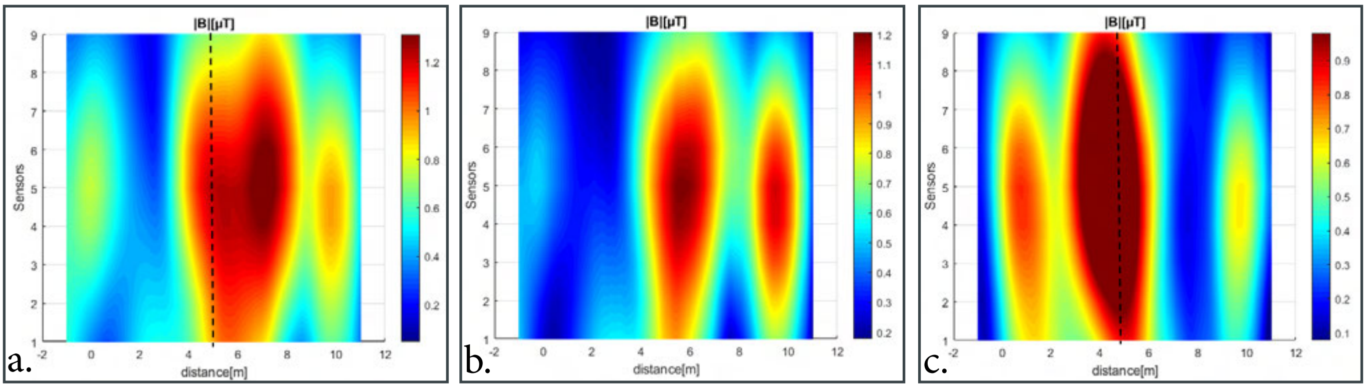

Figure 6: Intensity of the magnetic field induced by the tubes with dent a. 5% b. 10% c.15%. Sensor spacing is 25 cm

Figure 5: Dent with depth of 15%

and R2 show agreement between the experimental results and the simulation results.
The dents generated by this type of indenting are relatively soft (very high radius of curvature). It should be noted that there is an infinite number of shapes of dents. The appropriate method to classify the dents by family will be the subject of another study.

4. IV. RESULTS

In order to record the initial magnetic state of the three pipes selected for denting, magnetic measurements were previously made at a height of 90 cm. After the introduction of the anomalies, the pipes were measured again while maintaining the same position as during the first magnetic scan (initial state); i.e., the same upper surface and the same extremity of the pipe at the laser position 0 as in the first measurement.

The introduction of the dents on the three pipes caused a clear and visible change in their magnetic response at 900 mm (Figure 6).

The intensities of the magnetic field are not homogeneous between the three plots, mainly because the magnetization varies from one pipe to another.

The inhomogeneity of the magnetization along the pipe causes the maximum of the magnetic anomaly to be located not exactly at the point of the defect and also causes other peaks to appear.

In order to highlight the effect of the dent, the color bar is fixed at the maximum field intensity of the initial state (without dent). Therefore, we can highlight through a darker color the section which exceeds this reference value of the initial state. It is, hence, possible to detect the presence of the anomaly on the raw signal even with a 5% dent depth. It is important to note in these graphs that the magnetic impact (amplitude and extent of the magnetic signal) of the dent increases with increased depth of the dent. The comparison of the magnetic results before and after the introduction of the dent makes it possible to isolate the magnetic change caused by the defect in the pipe.

A relative analysis (difference between intensities of magnetic fields before and after the introduction of the dents) made it possible to extract the magnetic variation caused by the defect. This analysis allows elimination of the fluctuations due to the variation in magnetization. Furthermore, it highlights an important observation: the magnetic response of the dent with increasing dent depth.
The intensities of the variation of the magnetic field are 0.74 μT for 5% and 1.03 μT for 10% and around 1.31 μT for 15%, the sensors being 25 cm above the pipe. The increase of the magnetic signal as a function of the depth of the dent makes it possible to associate a magnetic signal with a type of defect (Figure 7).

These observations are of great importance for the deployment of LSM technology. Indeed, dents create a strong variation of the local remnant magnetization. The shape of the resulting magnetic signal depends mainly on the extent of the section affected by this change of magnetization, as well as the increase of magnetization generated by the dent.

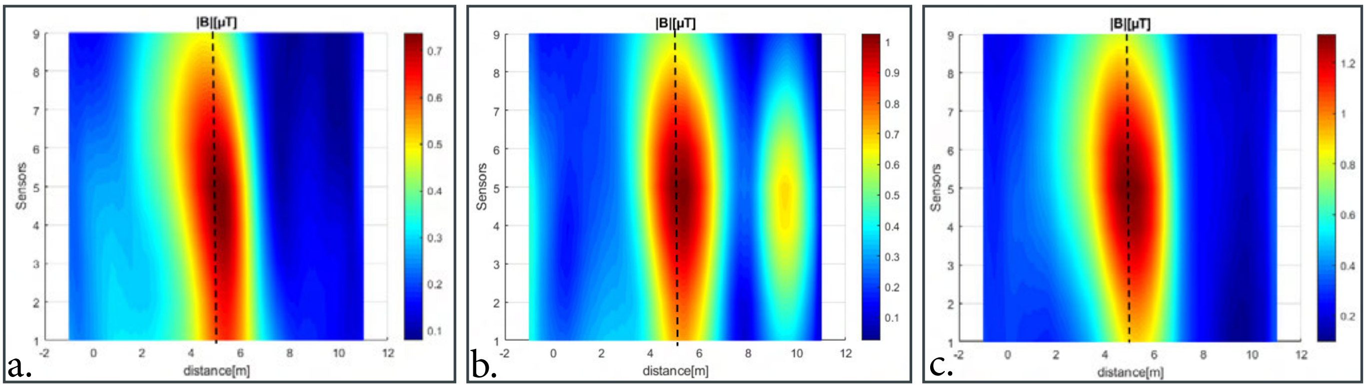

Figure 7: Difference of the intensity of the magnetic fields induced by the tubes (with dent – initial state) a. 5% b. 10% c.15%%. Sensor spacing is 25 cm

5. DISCUSSION

A dent is an irreversible plastic deformation of material. Dents cause variations up to the nominal mechanical stress (σ> 320 MPa) over a large section as shown previously in the finite element simulations. This modification of the mechanical properties (in elastic and plastic domains) leads to a modification of the magnetic properties. The results of the experiments reported in this paper make it possible to evaluate the evolution of the magnetic signal for a single type of dent as a function of the depth of dent. Magneto-mechanical coupling in the elastic and plastic domains remains to be established.

The relationship between the magnetic properties of steel and its mechanical properties is governed by a complex law. Moreover, the existence of a fundamental law in physics that could characterize this coupling is still unknown. Several previous studies have been conducted to solve this uncertainty. The best-known model is the Jiles-Atherton model [2], which links a uniaxial stress variation to a variation of magnetization in the same direction. This model is, however, limited to the uniaxial case and to the elastic field. It cannot be applied to the case of stress around a dent, which is multiaxial and goes well beyond the elastic limit. This experimental work was accompanied by a magneto-mechanical characterization study, which will be published elsewhere soon.

Skipper NDT has developed a signal processing algorithm chain to locate specific events on the pipeline such as welds, repairs, thickness changes, etc. It also makes possible to detect signal variations due to dents. The relation between the form/depth of the dent and the shape of the resulting magnetic signal reinforces the possibility of locating a dent and characterizing the type of dent in buried pipelines. The characterization process will be realized primarily through a machine learning algorithm and a library of magnetic signals corresponding to a multitude of configurations.

6. CONCLUSIONS

Dents are anomalies that could expose pipelines to high risk. This paper has highlighted the interest of using the LSM technology to detect this type of anomaly, which sometimes proves to be difficult to detect through active methods.

Generating dents with the same indenter at an increasing depth showed that the magnetic signal resulting from this type of anomaly increases with the depth of the dent.

This has also shown the lack of a linear relationship between the measured magnetic field and the mechanical stress in the metal. The magnetic signal depends mainly on the shape and extent of the anomaly.

A knowledge of the stress / magnetization relationship is very important in order to carry out simulation work and to generate the library of data necessary for the interpretation of the measured signals. Skipper NDT has carried out characterization work on test samples from pipe, in the elastic domain and then in the plastic domain in order to quantify the variation of the magnetization as a function of the mechanical properties (stress and strain). This magneto-mechanical behavior law is used to convert multiaxial stress distribution into remanence magnetization distribution essential to magnetic simulation. A 3D magnetic model entirely developed by the Skipper NDT team makes it possible to simulate several configurations and to understand several phenomena.

The simulation results corresponding to the experimental tests presented in this paper will be presented in a separate publication.

7. ACKNOWLEDGMENT

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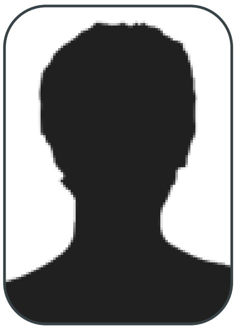

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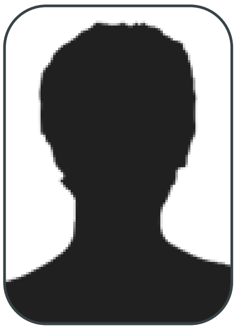

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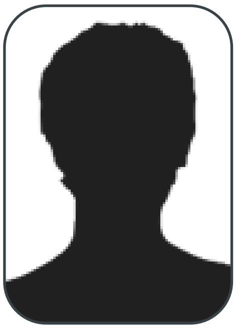

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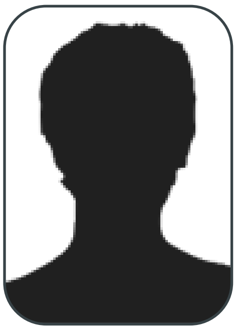

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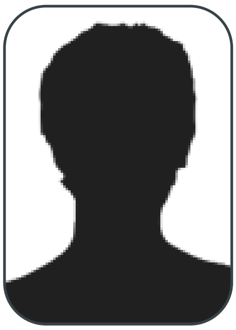

System Reliability Improved Through Fast-track Force Main Replacement

Kishen Prathivadi; Tim Monahan > Sewer Authority Mid-Coastside; SRT Consultants

Abstract

The Sewer Authority Mid-Coastside (SAM) transports and treats wastewater from several coastal communities in San Mateo County, California. In the spring of 2017, one of SAM's force mains, the Granada Force Main, experienced a series of ruptures that disrupted operations and negatively impacted local beaches. Due to its previous history of breaks, its age, and materials of construction, SAM initiated a program to replace most of the force main to improve system reliability, protect residents, and safeguard the coastal environment.

This challenging project was executed on a short schedule and a limited budget. SAM expedited the design process in parallel with surveying, condition assessment, biological assessment, wetlands delineation, and permitting. The design incorporated durable corrosion resistant materials such as high-density polyethylene (HDPE) pipe and appurtenances and unique construction techniques such horizontal directional drilling to accelerate the construction process.

1. INTRODUCTION & BACKGROUNG

The Sewer Authority Mid-Coastside (SAM) is a California joint powers authority (JPA) that provides wastewater conveyance and treatment services to its three member agencies: Montara Water and Sanitary District (MWSD), Granada Community Services District (GCSD) and the City of Half Moon Bay. SAM's service area is along the Pacific coast 30 miles (50 kilometers) south of San Francisco. The Intertie Pipeline System (IPS) is the backbone of SAM's wastewater conveyance system. It is comprised of a series of force mains, pump stations, junction structures, and interceptors that convey the majority sewage to SAM's wastewater treatment plant. Granada Force Main is the last pressurized segment on the IPS and is critical to transporting wastewater from the communities in Montara, Moss Beach, Princeton-by-the-sea, El Granada, and Miramar to the plant in Half Moon Bay.

The Granada Force Main consists of 8,800 linear feet (2.7 kilometers) of 14-inch (355 millimeters) ductile iron pipe. This pipeline was built in the late 1970s. The first 1,700 linear feet (520 meters) of the pipeline was lined with cured-in-place-pipe (CIPP) in 2012 after a pipe rupture occurred a few hundred meters downstream of the pump station. At the same time, four pipeline bypass stations comprised of pre-cast concrete vaults, isolation valves and air release valves were also installed at strategic locations to aid in maintenance and repairs if necessary. The bypass stations allow SAM to isolate portions of the force main and were valuable assets during the construction of the replacement force main.

In the spring of 2017, several breaks occurred on the force main between El Granada and Miramar due to cavitation caused by a malfunctioning surge tank and air/vacuum release valves. Damaging hydraulic pressure waves (surge) cause the water pressure in the pipeline to drop below vapour pressure causing air bubbles to violently collapse and destroy the pipeline's interior cement mortar lining and eventually the ductile iron pipe wall. Forensic assessment of the pipeline revealed consistent damage to the invert (bottom 20 degrees of the pipe's interior circumference) including coating loss and significant pitting of the metal. There was no evidence of deterioration or external corrosion on the remaining of the pipes.

SAM responded immediately to locate, uncover, and repair the force main breaks with emergency clamps. Collection system operators implemented their spill control plan to minimize adverse effects to the environment and receiving waters as well as safeguard public health at a nearby public beach popular for recreations. SAM also worked closely with State regulatory agencies to notify them of

Figure 1: Granada Force Main Overview

Figure 2: Cavitation damage on the bottom of pipe

the incidents, document mitigating measures taken, and estimate the volume of the sewer system overflow (SSO). SAM's pro-active environmental stewardship and cooperation with the authorities allowed them to negotiate less stringent and less financially devastating penalties.

2. METHODOLOGY

SAM also started to organize efforts to replace the problematic portion of the Granada Force Main at the same time. The following sections describe SAM's strategies to expedite the force main replacement, the results of SAM implementing these strategies, and lessons learned from implementing this project.

2.1. DETERMINING SCOPE OF WORK

After the force main break in April 2017, SAM immediately initiated replacement of the existing force main. The first step was to decide the scope of the project. SAM mapped all the historical main breaks and overlaid them on them on top of the force main alignment. This visualization helped to identify the most problematic segments. SAM elected to replace 5,700 linear feet (1.75 kilometers) of the force main between two the existing bypass stations. This work included new air/vacuum release valves (ARVs), blow-off assemblies, and surge tank at the pump station.

2.2. PREPARING FOR DESIGN

SAM simultaneously began topographical survey, biological assessment, and wetland delineation to expedite the preparation for final design. The wetland delineation revealed large areas of sensitive environmental habitat, two creeks and intermittent streams, several seasonal wetlands and dense riparian vegetation. The biological assessment indicated there were no endangered or protected species in the proposed construction area. SAM's engineers also walked the alignment before starting the design to better understand the existing conditions, identify utilities, note challenges (dense vegetation, stream, and creeks) in order to sufficiently identify these in the contract documents so that potential changes during construction were avoided. The preparations for design were completed in only one month through focused collaboration with SAM, its member agencies, utility companies, and environmental and survey consultants.

2.3. DESIGNING AND PERMITTING

Detailed design followed immediately after the completion of the topographical survey, biological assessment and wetland delineation. High density polyethylene (HDPE) was selected for the new pipe material because of its durability and ease of installation using conventional cut and cover and trenchless construction methods. This pipe material is typically black, but was specially fabricated for this project with a grey interior so that future internal CCTV inspection can be performed effectively. A tracer wire or detection wire fully insulated with Copper was also installed during the HDD operations to identify the pipeline later.

HDPE pipe is manufactured according to either iron pipe size (IPS) or ductile iron pipe size (DIPS). The IPS HDPE pipes have the same outside diameter as cast iron or carbon steel pipes. The DIPS HDPE pipes have same outside diameter of ductile iron pipes. DIPS HDPE pipe was selected considering readily available appurtenances such as repair clamps and tapping saddles that may be needed in the future. The nominal size of the new HDPE pipe was 16-inch (DR 11) so that the internal diameter would match the internal diameter of the existing pipeline.

To minimize the construction impact in the environmentally-sensitive areas identified, SAM designed the new force main to be installed by horizontal directional drilling (HDD). Sending and receiving pits were located outside of the designated environmental setback areas and the new pipe was installed at a minimum of 10 feet (3 meters) below the existing grade and deeper under water ways.

Since Granada Force Main parallels the Pacific Coast and bisects streams and creeks, this project is subject to more stringent State and County permitting requirements. Exemptions for certain local permits were granted since the work was considered replacement/repair as opposed to new construction. The planned use of HDD also streamlined the permitting process because SAM was able to demonstrate that no environmentally-sensitive areas would be disturbed.

The detailed design was completed by the end of August 2017, and the project was bid in September.

2.4. CONSTRUCTING NEW FORCE MAIN

Construction broke ground on this project in October 2017, only six months after the last force main break in April. SAM prioritized the submittal review for this project so that the contractor could order materials as soon as possible. The new force main was installed in multiple segments between the existing bypass stations. Above-ground bypass piping was installed so that sewerage conveyance was maintained at all times. The temporary pipelines used a specially designed circumferential restraining system that allowed for quick installation and dismantling. HDD also significantly accelerated the construction process allowing the contractor to install approximately 1,000 linear feet (305 meters) of pipe in just one day.

Despite some unforeseen field conditions, the construction reached substantial completion in March 2018. SAM worked closely with the contractors to resolve issues in the field in a timely manner. SAM also established and maintained a collaborative working relationship with the local residents, consulting engineer, contractor, and other stakeholders that kept the project moving ahead efficiently and kept change orders to less than 1 percent of the construction contract amount.

Figure 3: New force main being installed using HDD

3. RESULTS

The new force main was commissioned in March 2018, less than a year after the initial break in 2017. SAM successfully executed survey, design, obtained required permits, and constructed a new 5,700 linear foot (1,740 meter) force main in under eleven months at a cost of $2.0 million (€1.8M). The efficient execution of this project is based on simultaneous execution multiple task and collaboration with all parties. This collaboration resulted in an efficient construction process with change orders totalling less than one percent of the construction contract amount.

Additionally, SAM's power consumption at Portola Pump Station has been noticeably reduced due to the improved hydraulic capacity of the HDPE pipe material and the lowered static head of the new force main. The new force main has an expected service life of over 100 years which greatly improves the system's reliability.

4. DISCUSSION AND CONCLUSIONS

Construction of the new Granada Force Main and its appurtenances was one of the largest recent infrastructure projects undertaken by SAM. SAM's immediate response to the force main failures dramatically reduced the potential damage to the environment, risk to public health and safety, and punitive damages imposed by regulatory agencies. SAM's subsequent fast-track planning and implementation of unconventional and unique approaches during the design and construction phases made this project successful. These included simultaneous negotiation with State regulators, environmental assessment, topographic survey, and detailed design. Implementation of trenchless construction techniques significantly reduced construction cost, reduced construction duration, excluded the need for protracted environmental permit approvals, and eliminated the disruption of wildlife and waterways.

Water and wastewater agencies today must maintain consistently high levels of service for customers, protect the environment, abide by regulations, increase efficiency, and adapt to climate related uncertainty. This becomes more difficult as infrastructure exceeds its useful life and the capital cost for repair and replacement continue to climb each year. Agencies must strive for innovative approaches to solve their current and future infrastructure challenges.

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In the next Edition of **ptj:**

NOVEMBER 2020

5th issue of the ptj

The next issue of Pipeline Technology Journal (ptj) will be about comprehensive topics

This issue will feature papers from different companies from all over the world.

Event Calendar		
IPC - International Pipeline Conference	28 September - 2 October 2020	Calgary, Canada
Virtual Pipeline Summit (VPS)	7 October 2020	Online
Virtual Ports & Logistics Summit (VPLS)	4 November 2020	Online
16th Pipeline Technology Conference	15 - 18 March 2021	Berlin, Germany

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