SUBSEA PIPELINE INSPECTIONS

James R Dale MEng BSc(Hons) CEng MICE([1])

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ABSTRACT
The paper will discuss diving safety, practical considerations and methods for the subsea inspection of inshore pipelines. The author's experience over many years as an internationally known diving engineer, maritime civil engineer and inshore pipelines engineer will be highlighted with several examples of inspections and designs for maintenance on wastewater outfalls, cooling water intakes/outlets and other marine structures. A range of standard and new inspection techniques will be discussed. Reference will be made to a variety of regulations, diving safety codes and guidelines. The paper will not cover oil and gas related offshore diving.

INTRODUCTION
The world of diving is fascinating but the amazing fact about it is that not many people know about it. Is it still one of those dark secrets? For the diver it is most of the time. The majority of commercial inshore diving is in low to nil visibility water. For the client or non-diver looking at the diver's reports of what he saw (or what he thought he saw or felt) it is a mystery to understand what the report means. How does the diver convey what he has seen or touched into a written engineering report? There is a world of difference between a report written by the average diver and one written by a diving engineer. Having an engineer do a subsea pipeline inspection on (or even in) the pipeline, can make a huge difference to the impact of the report. The diving engineer has a knowledge of materials, structural analysis, pipeline hydraulics and is trained over many years in design and construction.
So what is this paper all about? It will try to inject common sense, illustrate some experiences and most importantly be very practical; all with an engineering flavour. Some basic procedures, guidelines and standards will be suggested. A review of diver health and safety will be followed by plant and equipment, dive pre-planning, operations and a look at different pipe materials. Then a discussion on a wide variety of inspection techniques, some "tips 'n tricks" and will precede a review of work experiences and a practical view of designing for maintenance together with a vision for the future. The whole idea of a subsea inspection is to tell the client what is down there in the most professional way and advise on the best way to maintain an expensive asset.

HEALTH AND SAFETY
Diving Medicals - A commercial diver using surface demand diving equipment (SDDE) has to carry numerous items of gear with him as he enters the water. This total extra weight that a diver has to carry is in the region of 25-30 kg out of the water, which can amount to an extra 25-40% of the diver's body weight. In order to be able to dive with this load, the diver must be fit and to check this the diving regulations in most developed countries call for rigorous annual commercial diving medicals. These medicals involve assessment of the heart, lungs, body joints, ears, eyesight and various other tests. Ventometer and audiometric tests are performed together with a full electrocardiograph before and after a standard short physical. The hyperbaric medical specialist will then issue a medical certificate saying the diver is fit to dive and enter the outcome plus expiry date and signature into the diver's logbook. Many divers in developing countries do not have annual medicals. It is most essential that procedures for it should be considered in the interest of the diver and his employer. An experienced diver is not someone an employer should wish to lose. During a diving facilities project assessment in Pakistan both divers and doctors (who wished to be trained in hyperbaric medicine) were tested for their diving medical knowledge.

[1]Consulting Engineer, Horsham, UK - E-mail: james@dale-consulting.co.uk

Diver first aid courses and diving medicals were recommended for the divers and a special commercial diving medical course in Australia recommended for the doctor, who would then be qualified to perform diving medicals for the divers [i].

Diving Regulations - The current UK Diving Regulations [ii] [iii] in force since 1997 have greatly improved the safety of divers. They were designed to be less prescriptive and more goal setting in principle than the previous 1981 Regulations and include a set of approved codes of practice for different areas of commercial diving (e.g. inshore, offshore, media, etc.) Diver training grades in UK are now offshore diver, inshore air diver and professional SCUBA diver (for fish farming, etc.). Diving using self contained underwater breathing apparatus (SCUBA) is now considered not a valid option in UK for commercial divers (inshore and offshore) unless there are good reasons like excellent visibility and minimal risk. One of the main points of the regulations is the risk assessment, which should be highlighted in the Dive Plan. This is to be considered an important document which, if every diving contractor completed, would go a long way towards a far more efficient diving operations than presently occur in some parts of the world.

Diver Training - Basic training for divers is another area where great emphasis has always been placed. Major international diver training facilities exist in various countries around the world such as UK, USA, France, Singapore, Australia and South Africa. The training covers a wide range of tasks in and out of water. Upon completion the diver is awarded a lifelong diver training certificate. One of the items removed from the UK diving regulations is the requirement for a diving first aid course. This may suit the diver working in UK where 'on call' emergency services are reasonably close. However, for divers working in foreign lands such medical facilities and expertise may not be readily available. It is therefore recommended that all divers attend a specialised diving first aid course at least every three years during their working life. Whistler and Larn's manual [iv] and the Submex's handbook [v] are excellent guides to diving for the novice diver.

Hazards - The hazards on subsea pipeline inspections are generally similar to those on any river or marine structure. As long as there is good access, the diver has plenty of air and the communications work, the dive should be a safe one. However that is not always true. In river control structures high flow velocities near gates can be a huge danger to divers, trapping the umbilical and forcing the diver against a gate. A fatal accident occurred in Pakistan where a diver on SCUBA with only a rope to the surface became jammed under a partially opened gate behind a dam. With velocities in excess of 20m/sec. it was impossible for him to extricate himself and drowned within metres of his team. No amount of pulling on the rope helped him. Other hazards include long, small, old culverts; shipping; debris; visibility; pressure to complete the work; busy site; cranes; marine construction crafts. Diving is dangerous and the hazards need to be understood.

Key Diver Safety Points – There are many factors which contribute to either a safe or a non-safe dive. The table below illustrates the various elements of a diving operation, which the diving engineer/inspector/contractor will need to consider.

Water depth	Work (Technical)	Equipment (Type)	Plant (HP bank/LP Compressor)
Supervision	Weight/Buoyancy	Hazards (Ships, Debris)	Qualifications
Safety Harness	Site conditions	Knife	Fins
Waves	Access	First aid	Mask type
Safety line	Air supply	Dry suit	Communications
Emergency procedures	Visibility	Tidal/River current	Weather

Table 1 – Diver Safety Points

Which four are considered to be the most important? Many diving supervisors were asked which four diver safety points they considered to be the key ones. The resulting answers are to be found at the end of this paper. These key diver safety points highlight the serious nature of commercial diving. It is not just about the work to be done [vi].

PLANT AND EQUIPMENT

In order to ensure the diver has air, communications and feels safe, an array of plant and equipment is required to support both the diver and the diving team.

Plant - The major plant items normally required include a vessel (see Figure 1), high and low pressure air compressors, air banks, control panel and decompression chamber (if needed). Maintenance of the compressors and testing of cylinders and calibration of gauges should be a regular task.

Figure 1 – A diving vessel offshore Lebanon

Diving Equipment - As a typical example the commercial diver would wear a dry suit, a safety harness (including lead weights), an emergency bail-out cylinder, a full face band mask or hat with communications (comms.), a knife, fins (or boots if working in one area), gloves, an umbilical containing his main air, comms., pneumo and safety line. If the umbilical is the twisted lighter weight type, no safety line is required. Checks on wear and tear should occur on a weekly or monthly basis.

Diving Masks – There are only a limited number of companies specialising in mask design and manufacture. Some practical comments on those masks, which are in common use, is given below.

Interspiro or Aga Divator Mk II – An old favourite with many die hard divers but not as common in use as the KMB10. Once got used to, it is a great and simple mask with positive pressure to steady the mask and very user-friendly generally. It is not good for heavy work though. Interspiro Ltd is the designer and manufacturer.

AH5 – Divex's latest hat in the AH range with improved visibility, waterproofing, flexibility and ideal for polluted waters [vii].

The Exo26 and ExoBR – A favourite with a few but not as popular as it should be with commercial divers, who find it too fussy on the regulator needle settings. The new BR version has solved that problem with a new balanced regulator. However the EXO26 is a wonderful lightweight mask and easy to put on or take off. It can be used with SCUBA (plus communications) and SDDE.

KMB10 – The original standard mask for commercial divers. In great use all over the world, even though Kirby Morgan Dive System Inc. have stopped manufacture. Spares are still available.

KMB 18B and 28B – The new masks are very similar, replacing the KMB10. Generally better and lighter than the KMB10 and easy to take apart and replace items and comms. They can be used for both air and mixed gas diving.

KMB Superlite 17B – This hat is for use on construction sites. It is very safe having a hard shell to protect the diver's head and the comms. are excellent.

The mask must be clean and must fit snugly and firmly. Masks do leak and the diver therefore needs to be aware that this, in itself, is not a problem as long as he has air and the leak is tolerable. However, if water leakage into a diver's mask occurs when the diver happens to be working on an inspection inside a pipeline, it is more serious and the dive should be aborted. In some situations diver retrieval back to a shore dive station or a large diving

vessel may be too arduous. This can be resolved by having an inflatable boat to provide safety cover and ensure safe return of the diver.
However the most important element of plant and equipment is maintenance. Regular checks on all plant and equipment including the diver's personal gear is absolutely essential for the diver's survival. Looking after the plant and equipment is one of the most basic duties of the diving supervisor and the team generally. Clients should insist that diving contractors keep all their plant and equipment up to a high standard. Clients can visit the contractor's yard to check on calibration/testing/maintenance certificates and records.

DIVE PRE-PLANNING
The client will provide a workscope or brief for the pipe inspection. The site should be assessed for location, water depth, diver access, weather, time of year, client's requirements, risk and type of diving plant required. If the price is right and the tenderer's capability and procedure satisfactory, the diving contractor or engineer wins the contract and starts his risk analysis. To do this the Dive Plan is filled out. The Dive Plan contains who is doing what for whom, where and why. The Plan lays out the team names, the diving equipment and plant needed, the drawings supplied (and other relevant information) and what insurances are required. Lines of communication are agreed and then the risk assessment on the hazards and their likelihood of occurrence are estimated. Pre-planning must include items like who turns off the cooling water pumps and who controls the keys or authority to turn them on again. In reality it has to be the diving supervisor who has the keys so no one can accidentally turn on the cooling water (CW) pumps when the diver is still inside the pipeline or inspecting the diffuser ports. The author got blown 10m backwards quite violently once many years ago when inspecting a 250mm diameter port on a moderately deep long multi-port CW outlet diffuser. The advantages of being attached to an umbilical quickly became obvious. Confusions can occur and hazards are always present, but they must be minimised. The Dive Plan is not a fixed entity but strictly under the control of the diving supervisor, however it is agreed and signed by all parties. Without pre-planning the dive many mishaps could occur, all wasting time, costing money and impinging on health and safety.

DIVING OPERATIONS AND CONTROL
The Dive Plan is carried forward into the operations and control stage. This is the serious part of the diving and is where the responsibility stops. Under UK law, it is the diving supervisor who is responsible for the diving operation, not the client or the diver in the water. The UK's Association of Diving Contractors supervisors manual provides helpful advice and guidance for the diving supervisor [viii]. The supervisor has to know what the diver is doing at all times as well as monitoring the time, air supply (via the control panel), local hazards (ships) and keep a watchful eye on his nearby team. His duty is to assist the diver in his subsea task as well as tell the diver what to do if the diver runs into a problem. In the water there is no need for a diver to wear a watch as time keeping is under the strict control of the diving supervisor. The most popular set of diving tables used by diving contractors and engineers is the US Navy Diving Manual [ix]. These comprehensive tables although not the safest are well known and experienced diving supervisors understand their weak points. The larger offshore international diving contractors will often have their own tables.

PIPE MATERIALS
There are several different pipe materials that can be used in pipeline designs. By list they include steel, glass reinforced plastic (GRP, called fibreglass reinforced plastic FRP in USA) both spun and centrifugal types, medium density polyethylene (MDPE), polyvinylchloride (PVC), precast reinforced concrete (RC) (pipe, culvert and immersed tube), prestressed precast reinforced concrete (PC), steel cylinder reinforced concrete, aluminium, spheroidal cast iron and ductile iron. Aluminium pipes are not used in a marine environment due to their lack of strength, lightness, softness and expense. Spheroidal cast iron and ductile iron are being replaced across the world in favour of modern materials. The steel cylinder RC pipe has had a limited popularity around the Mediterranean although it has had a chequered history due to alleged steel corrosion of the cylinder but in principle it is a sound pipe if designed prudently. The joints need careful inspection. The most popular materials today are RC, steel, GRP and MDPE pipes.

Concrete - A PC pipe was used successfully on a Greek outfall, having been cast vertically! It was then connected into a string of 3 to 4 pipe lengths some 75m long and installed underwater. RC pipes are very popular in USA and special equipment has been designed to install them, namely the ‘Horse’ steel frame [x]. Inspection of the joint integrity is needed after seismic shocks because the joints are spigot/bell and socket type push-fit joints and can come apart. Some USA outfalls have specially designed aseismic joints to resist the horizontal and sideways thrusts of an earthquake.
RC pipes can be made in sizes up to 4m diameter and even larger but they can become problematic for handling and a project takes on another dimension in complexity. Concrete is a good material to use underwater because of its great durability. Concrete tests in 2001 on a UK offshore navigation tower in [xi] proved that submerged concrete can maintain high strengths even after 80 years. An immersed tube RC culvert type box design was used successfully on a cut and float CW inlet at Sizewell B [xii]. The seabed has to be prepared as level as possible for concrete culvert or pipe laying underwater and checking of joints becomes important.
Steel - Steel pipes in sizes up to 3000mm can be weld together into strings and pulled into position. They are strong, durable and have long been used in oil and gas pipelines. However they require extensive corrosion protection and are not cost effective in short length outfalls due to the major plant necessary for their installation. The larger sizes suffer from ovality in site fit-up. Concrete weightcoated steel pipes were for some time the chosen pipe for treated sewage outfalls until newer materials such as GRP and MDPE arrived on the scene.
Plastic - The popularity of these flexible pipes by clients, designers and contractors is astounding. PVC (or unplasticised polyvinylchloride) pipes are generally employed on small size intakes and outfalls in lakes and under private ownership. They have been used on marine risers and ports on large outfalls with flanged joints [xiii] but become brittle. They do not have the wide size range, jointing variations or strength capabilities as the GRP and MDPE pipes and also seem to attract marine growth.
GRP pipes are manufactured by the spun or centrifugal methods. The centrifugal or Swiss ’Hobas’ produces a stronger pipe, more durable and better suited to the marine environment than the spun version and can be made in diameters up to 2.5m. However the spun GRP pipe appears to be the easier to make and thereby the most popular of the two options to install. The spun pipes are made in many countries, including Turkey, with good standards of manufacture. One of the big drawbacks though with the spun version is its thin wall and therefore its inability to take too much bending and torsional stress.
On land the laying of GRP pipes is a fussy procedure requiring careful backfilling. Underwater these problems can be easily compounded. The author is not convinced, particularly for large pipes greater than 1200mm in diameter, that these spun pipes should be used. The difficulty of joint integrity under all conditions (including earthquake shocks), their lightness (when some weight underwater is a good thing for stability), inherent lack of strength, ovality at large sizes and their ablity to delaminate should be seriously considered before a final decision is made. Otherwise the diver inspecting these pipes will bring tales of woe.
The same goes for MDPE in a general sense, although the joints for MDPE pipes are be heat welded onshore and made into long strings, with less attendant subsea joints, to be floated out in 400m lengths and sunk into prepared trenches. It is a very flexible pipe with many joint options, can take up unevenness in a trench and is not such a ‘fussy’ pipe as GRP. The manufactured diameters are increasing every year for this pipe with 1600mm or more now possible, which would be adequate in single or twin form for most inlets or outfalls. MDPE also makes a good riser or port pipe material in conjunction with another main pipe material. It can lend itself to a fail-safe type of design, easily replaceable if damaged.

INSPECTION

Inspection methods - There are two inspection methods. Either the diver goes in the water or a remotely operated vehicle (ROV) is used. For projects that are non-oil/gas industry related, ROV’s would generally not be used. This paper is about diver inspections. ROV’s are used occasionally. The author hired an ROV to inspect inside a deep pump shaft in UK. The reason was two fold: the shaft bottom was 60m down and the access was not good. Even so an air diving team was on standby nearby in case the ROV got stuck! The team was not used. Good visibility and lack of debris are needed really for an ROV to operate successfully. Internal and external remote electronic sensing systems are available using sonar and stills/video cameras but they are expensive to use. For internal inspections of pipes less than 1200mm diameter, they may be the only option.

Divers generally use two underwater inspections and these are carried out either separately or during the same dive. One is a general visual inspection (GVI) and the other a close visual inspection (CVI). The main difference between these two inspections is the detail result obtained. A GVI is the most common. It gives a general impression picking up points for a more detailed look if required by the client or for the next diver to investigate. The CVI concentrates on selected areas with the use of subsea inspection instruments (see Figure 2).

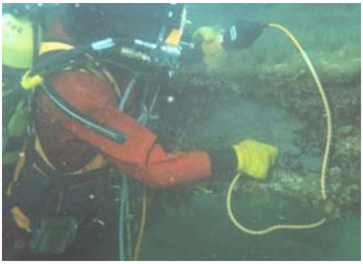


Figure 2 – Ultrasonic test of steel member by diver in UK

For example a GVI might pick up scour under an anchor block, wear on an anode, missing bolts on a flange, rust on a steel structure or cracks in a concrete structure. The CVI would entail measuring the scour hole and assessment of the local stability of pipeline and anchor block to decide whether it needs repairing and possible methods to be used for the repair. The CVI would record the wastage on the anode with CP readings, count the flange bolts and measure the bolt diameters and bolt length and measure the flange gap all round. The concrete cracks would be assessed for location, extent, width, depth and steel reinforcing bar exposure or rust marks [xiv]. The use of an ultrasonic wall thickness meter (UT meter) would enable readings of the remaining wall thickness at the rusted and non-rusted areas of a steel pipe, pile or other subsea steel structure. Photographs and video footage could be taken in a GVI or a CVI depending on the extent of work. The UK's Institution of Structural Engineer's guide to inspection is intended to set a standard for marine structural inspections [xv].

Inspection Tools - There is a wide range of inspections tools available to the diver [xvi]. Apart from using the diver's own eyes and hands (and trained imagination in very low to nil visibility), the most useful pieces of equipment are the diver's knife, 3m or 5m retractable tape, chipping hammer, marine growth scraper and a short (230mm long) spirit level. Other more technical equipment or tools include the cathodic potential (CP) meter, ultrasonic wall thickness (UT) meter, crack detection equipment, stills camera, and video camera. Torches generally come in two sizes, big or small: a small torch can be carried by the diver whereas a big torch can be cumbersome and problematic and should therefore be passed down to the diver or tied off when not in use. The question whether to use rechargeable or standard batteries is always debatable but generally replacement batteries are more practical as long as the diving supervisor ensures that spares are readily available. Figure 3 shows a selection of inspection tools used on a diving inspection in Ireland.

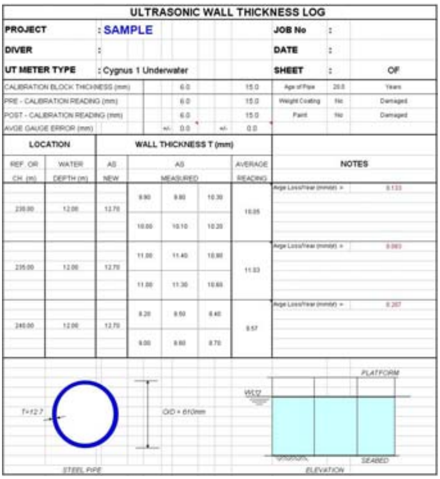
Figure 3 – Stills and video cameras, UT and CP meters

The use of subsea video cameras for inspection was proven on a concrete/stone wall crack investigation job in Liverpool, UK. The diver could not see the crack because the visibility was less than 200mm so the diving engineer monitored the crack by advising the inspection diver what line to follow with a low-light camera. These cameras can focus down to 100mm; beyond the human eye in the water. The underwater alternating current field measurement (ACFM) crack microgauge can size up cracks (Figures 4 and 5). It is a most useful tool where cracks are very small or difficult to see with the naked eye, although expensive to use. The technique uses the surrounding variations in an input alternating current electromagnetic field to predict crack depth.

Figure 4 – ACFM topside equipment

Figure 5 – ACFM subsea equipment

Inspection Logging - The simplest way for the diving supervisor to log or record the feedback from the divers is to document this information on ordinary lined paper. The inspection diver or diving engineer can then reformat the information after the dive. For inspections where UT and CP readings are required, it is essential to calibrate the equipment before and after the dive. Calibration is done in seawater with a zinc test piece. The UT meter also requires calibration with special steel blocks of known thickness (10mm, 20mm, etc.). Above water the meter needs a suitable couplant to obtain a reading. A sample UT log sheet can be seen in Figure 6. These standard log sheets tidy up a report instantly making it professional, easily understood and consistent. Log sheets can be supplied for photo shots, video footage, marine growth, UT, CP and any other recorded data.



ULTRASONIC WALL THICKNESS LOG

PROJECT	: SAMPLE	JOB No	:
DIVER	:	DATE	:
UT METER TYPE	: Cygnus 1 Underwater	SHEET	: OF

CALIBRATION BLOCK THICKNESS (mm)	6.0	15.0	Age of Pipe	20.0	Years
PRE - CALIBRATION READING (mm)	6.0	15.0	Weight Coating	No	Damaged
POST - CALIBRATION READING (mm)	6.0	15.0	Paint	No	Damaged
AVGE GAUGE ERROR (mm)	+/- 0.0	+/- 0.0			

LOCATION		WALL THICKNESS T (mm)					NOTES
REF. OR CH. (m)	WATER DEPTH (m)	AS NEW	AS MEASURED			AVERAGE READING	
230.00	12.00	12.70	9.90	9.80	10.30	10.05	Avge Loss/Year (mm/yr) = 0.133
			10.00	10.10	10.20		
235.00	12.00	12.70	11.00	11.40	10.90	11.03	Avge Loss/Year (mm/yr) = 0.083
			11.00	11.30	10.60		
240.00	12.00	12.70	8.20	8.50	8.40	8.57	Avge Loss/Year (mm/yr) = 0.207
			9.00	8.80	8.70		

Figure 6 – UT log sheet

For example on a large scale pile inspection in Kuwait, the average thickness of hard marine growth amounted to 150mm all round the precast concrete piles thus increasing the piles by up to 60% in diameter. The extra wave forces on these piles due to this excessive marine growth could never have been considered by the designer. It was recommended to be removed, which was predicted also to be a slow and laborious job. Regular maintenance inspections would have highlighted the growth and removal would have been easy.

TIPS 'N TRICKS

A commercial diver should never jump into the water, it is always dangerous. He should climb down a ladder unless he can clearly see into the water that there are absolutely no hazards. Placing a steel retractable tape (3m/5m long) in fresh water during a long series of dives over several days will make the tape last longer. Measurements in zero visibility conditions can be done with a short measured notched aluminium rod; the diver then feels his way down the rod and notes the notch marks. Tools like the hammer, CP and UT meters, camera and torch should all be attached to the diver with a short lanyard of 500-600mm length and a 75mm carabiner. The diver's knife has a multitude of uses and should always be carried on inspections.

The CP meter should be placed in a bucket of seawater at least one hour before the diver uses it. Vaseline or petroleum jelly can be used instead of the proprietary couplant for expelling the air and ensuring good contact to take a UT meter reading above water. Use weighting factors on the readings for marine growth of soft and hard to obtain the actual increased thickness to add to the pile's outside diameter for wave force calculations. Soft marine growth (hydroids, dead man's fingers) has less effect on wave forces than hard marine growth (mussels, barnacles). In order to have a margin of safety on umbilical length, the diving supervisor should retain 5m from being released into the water unless the diver is in trouble. The UK regulations require the standby diver's umbilical to be 10m longer than the working diver's umbilical.

WORKING EXPERIENCES

On a large CW pipeline an 'out of alignment' had occurred during installation. As part of the GVI, the diving engineer was required to assess the degree of fall. With only basic equipment available at the time, a cleaning stick, a short spirit level and a 5m retractable tape provided the result of 32° as shown in Figure 7.

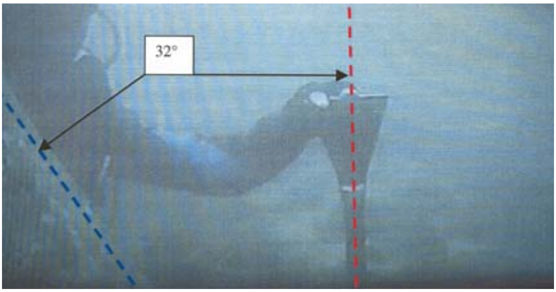


Figure 7 – Subsea measurement of large pipe out of alignment

On a Southern North Sea pipeline inspection in 25m water, the diver found wide scrape marks on the seabed. What he did not know at the time was that another diver had previously observed several damaged concrete anchors exposing the 20 year old steel gas pipe, which was undermined and spanning up to 10-20m. The subsea engineer on the diving vessel eventually discovered on the next dive that the pipe had been 'snaking' its way back and forth across the seabed with each tide because it lacked fixity. After a rapid stress check on the curvature of the pipe, an anchor design was proposed and the pipe re-stabilised. Strong currents alone had caused the damage over a short number of years.

The weather dogged the subsea repair of an offshore navigation tower, damaged after a ship collision, from the commencement of work on site. The project team decided that it was a matter of identifying what tasks had to be done in a certain time due to unpredictable long period waves coming in from the North Atlantic and the strong tidal current, in which no diver could work. This is a common problem in diving, where waves and currents can delay underwater jobs constantly. As much pre-planning, practical design and pre-fabrication of units was done above water so that divers spent the minimum amount of time in the water. It was vital to choose an experienced diver with an understanding of what had to be done and then supply him with the right tools for the job quickly.
Operatives on a power station noticed that the water levels in the CW inlet chamber on land had dropped by 450mm over time. An investigation was started using a diving engineer with pipeline knowledge. The decision was made to inspect the inlet line, which revealed an extensive build-up of mussels and to a lesser extent barnacles. The calculations in Table 2 examined the theory (in simple terms) to see if it matched the practice.

Objective

To see if a head loss of 450mm in the Cooling Water (CW) Inlet Forebay/Inlet Chamber could have been caused by the barnacles and mussels growth of up to 30mm thick on the internal surface of the inlet pipeline.

Input Data

CW offshore pipeline length = 520m, Internal diameter of GRP pipe = 2500mm, Flow 9400 litres/sec.

Options

(a) Try roughness coefficient Ks = 0.06mm at 15°C for GRP as likely Ks value assumed by pipeline designer, if presumably designed to international standards.
(b) Try present condition Ks = 3, 6, 15, 30mm to match 30mm marine growth at 15°C.
(c) Assume match of hydraulic gradients = 450mm / 520m
= 0.86 mm / m

This is the difference between the original design and the actual situation now. Therefore the target hydraulic gradient is 0.86mm / m

Output

Calculations produced for various Ks values with the sea water at 15°C are as follows:-

Ks (mm)	Hydr. Gradient (mm / m)	Head Loss (mm)
0.06	0.76	395

This is the original design perhaps. Add 0.86+0.76=1.64mm/m
Need to find a value of 1.64mm/m or 852mm

Ks (mm)	Hydr. Gradient (mm / m)	Head Loss (mm)
3	1.54	800
6	1.84	956
15	2.39	1242
30	3.01	1565

Conclusion

The matching Ks value appears to be 4.0-4.5mm. Equivalent Ks values for 50%/50% mix of 30mm thick of barnacles and mussels would be in the region of 15mm. The related velocities of 1.9-2.0 m/sec. are acceptable. The pipeline designer would possibly have assumed the head loss of such marine growth to be higher than 450mm. It would be useful as a check to measure and compare the actual still sea water level with the Forebay water level when the pumps are running. It partly explains the level drop in the Forebay if inlet and outlet losses are considered as well.

Table 2 – Example hydraulic calculation of CW inlet pipeline following diving inspection

A concrete weightcoated steel pipe marine outfall in Southwest England had been pulled across a 30m long low area in the seabed at the 24m deep diffuser end. It was necessary for the diving contractor and the supervising diving engineer to find a solution. The seabed was considered stiff enough to take a series of fabric grout-filled bag support piers up to 1-1.5m high x 2m wide x 2m long specially made to suit a 4-point support to the line. The centre supports were fixed and filled first to take the weight followed by the rest. One of the important elements of a subsea pipeline inspection is for the data to be recorded properly

On a lighter note during a pile inspection in Ireland, the diver experienced a peculiar brushing sensation and felt his fins being pulled off (the visibility was zero). He informed the diving supervisor that he was being attacked and surfaced quickly. The surface team were falling about laughing when they told him it was just a harbour seal feeling rather amorous. Other adventures included a diver being covered in Krill (a small shrimp which whales eat in huge volumes) on a Southern North Sea dive. He had a heaving mass of shrimps all over his suit and equipment. A good hosing off cleaned him but some had got inside his suit around the neck seal and he squirmed for ages.

DESIGN FOR MAINTENANCE

There are many issues to be addressed when designing a pipeline for easy maintenance. To design a pipeline requiring 'no maintenance' is probably impossible unless it is a pipeline specifically designed for a short lifespan of, for example, 5 to 10 years or it is a small works pipeline. All marine structures require inspection and maintenance in order to preserve them for their working life. Unfortunately the reality is that some clients expect marine structures and pipelines to look after themselves.

This then is the pipeline designer's dilemma. First to attempt a pipeline design that requires little or no maintenance, secondly to minimise the construction cost to the client and finally to allow divers access to the external and internal surfaces of the pipe, inlet, outlet structures or outfall diffuser section. The choice of pipe material is the obvious place to start but once decided the remaining elements will be easier to slot into place.

Access - In pipelines with diameters less than 1200mm, diver access internally is too dangerous. The inspection of smaller pipes can be undertaken by ROV or CCTV robot units, although manholes should still be provided for those units. In order to inspect inside a large subsea pipeline, which has marine growth or other slime build-up, cleaning must usually occur first. Divers can do it but due to diver burn-out it takes time. Burn-out is when a diver has no more in-water time left for the day and cannot dive again until the next day. Remote machines like the Reinhart RRR cleaning equipment (www.reinhart-sa.ch) travelling at up to 0.9metres per second can pass through 75-2400mm pipes and negotiate 90° bends. The pipe would need to be designed to take the machine (i.e. suitable entry and exit points).

Underwater manholes for robot entry or recovery can be spaced at 400m centres and may have to be designed for particular machines but for diver access they should be spaced at no more than 150-200m. However, economics of design and lack of 'diver' understanding often result in manholes not being considered or spaced at huge distances apart [xvii]. SDDE divers inside pipelines cannot be expected to normally swim more than 100m each way of an access, because it is so tiring. In 10m of water a 100m swim requires a 125m umbilical length at least for safety. The corners of all 45° and 90° bends (the most common angles) inside pipelines should be rounded to at least 100-150mm radius, if possible, to prevent umbilical damage and to reduce the effort for the diver in manhandling the umbilical as it passes around the bend.

Access gates to offshore CW inlet structures should have two simple removable bolts and a minimum 1000mm size hinged gate for easy diver entry. In order for a fully kitted diver to access an inlet chamber on land, a strong 600mm wide steel ladder, at least 250mm from the wall to which it is fixed, with two strong hand holds 1m high at the top is ideal. Very often a standard ladder is installed, again for economy and lack of understanding about diver requirements. Access back onto a boat is tougher than climbing a ladder in calm water as seen in Figure 8.

Figure 8 – Difficult diver retrieval in heaving sea

Depth - Realistically in order to reduce the cost of diving operations it is necessary for the invert of the pipe or seabed, depending on whether the diver needs to enter the pipe, to be no more than 40m deep at high-water. Any deeper than 40m seriously affects the in-water productive time for the diver, the team has to be larger and the costs starts to rise. Past 50-60m mixed gas diving systems will need to be employed and then the diving costs will be high. It is not advisable for working inshore air divers to be diving at greater than 40m. It is known to occur often on deepwater diffusers but it is not medically sound for the diver. It is expensive and non-productive for the client and requires a high level of expertise by the diving team with good plant and equipment. The expertise by the diving supervisor is whether to use bounce-diving, surface oxygen, in-water or standard decompression tables for the operation and whether the team will contain enough members before divers are 'burnt-out' for the day.

Valves - Tideflex valves, as made by the Red Valve Co. USA, are of enormous value to the pipeline designer and the diver. Tideflex valves used on diffuser ports have been one of the great steps forward in diffuser design and maintenance. Their simplicity and basic ruggedness belie their huge effectiveness and ease of maintenance. In fact if checked regularly, they should require little cleaning or refixing as long as they have been designed properly and the immediate vicinity is considered.

Flanges - Bolts to flanged manholes, ports and riser should be stainless steel wherever possible for a long life and easy removal and replacement. For electrical discontinuity between steel flanges thick,hard neoprene rubber washers are ideal and for pipes with corrosion protection systems electrical continuity over flanges with rubber gaskets is ensured with braided stainless steel straps connected bolt to bolt.

VISION FOR THE FUTURE

Vision is the operative word. One of the biggest problems underwater for the inshore diver whether on a pipeline or a structure is being able to see the job. Therefore the best equipment for the diver is something that can pierce the dark gloom in front of him. The equipment could send out signals from a sonar device built into a diver's mask or hat and be read out as a full 3D image in his mask rather like the head-up displays in modern fighter planes. Devices like this are in the research stage but have not yet reached the commercial market yet. If they can be reasonably priced, it will be a huge improvement on inspection quality and diver safety.

A re-usable and diver-friendly tape measure would be a great step forward. Divers' fins need to be designed to be easier to put on and take off but not accidently. Advances in dry suits and gloves should include measures to make them easy to put on and take off whether wet or dry. New microphones and earpieces could improve the communications between diver and surface. The wiring in most hats is a constant source of problem and fiddly to repair for the supervisor. Push-fit type reliable wet connections would be ideal. The present push-in fittings are not reliable for inshore diving. Most diving contractors still use binding posts and bare wire connections even with their likely signal loss.

COMMENT

Diver safety comes first as new regulations increasingly emphasise. The pipeline inspection comes second. Some clients understand this but not all. If the client wants a safe dive with a professional inspection, then it must ask the diving contractor to strictly adhere to internationally safe diving standards (for example no SCUBA unless good visibility and safe to do so) and be willing to pay for this high standard. Subsea pipeline inspections have improved over the years but the vast majority of pipelines once laid are never inspected unless something goes wrong. Designing for maintenance is one thing but ‘designing for no maintenance’ is quite a different matter. Regular maintenance inspections of pipelines are essential as a preventative measure.

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Answers to Key Diver Safety Points – Air Supply, Communications, Access and Hazards.

BRIEF CAREER BIOGRAPHY

JAMES DALE

James Dale obtained a Bachelor's degree in civil engineering at Brighton Polytechnic (now University) in 1971 followed 8 years later by a Postgraduate Master's degree in maritime civil engineering at the University of Liverpool. He is a Chartered Engineer and has been a commercial inshore air diver since 1973. He has worked in subsea, pipeline, river, coastal and maritime civil engineering, mainly for consulting engineers, (with short periods in contracting), as client's representative, designer, site engineer, project manager and diving engineer. His experience covers 30 years practice in UK and many overseas countries. He now works as an independent consulting engineer.

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