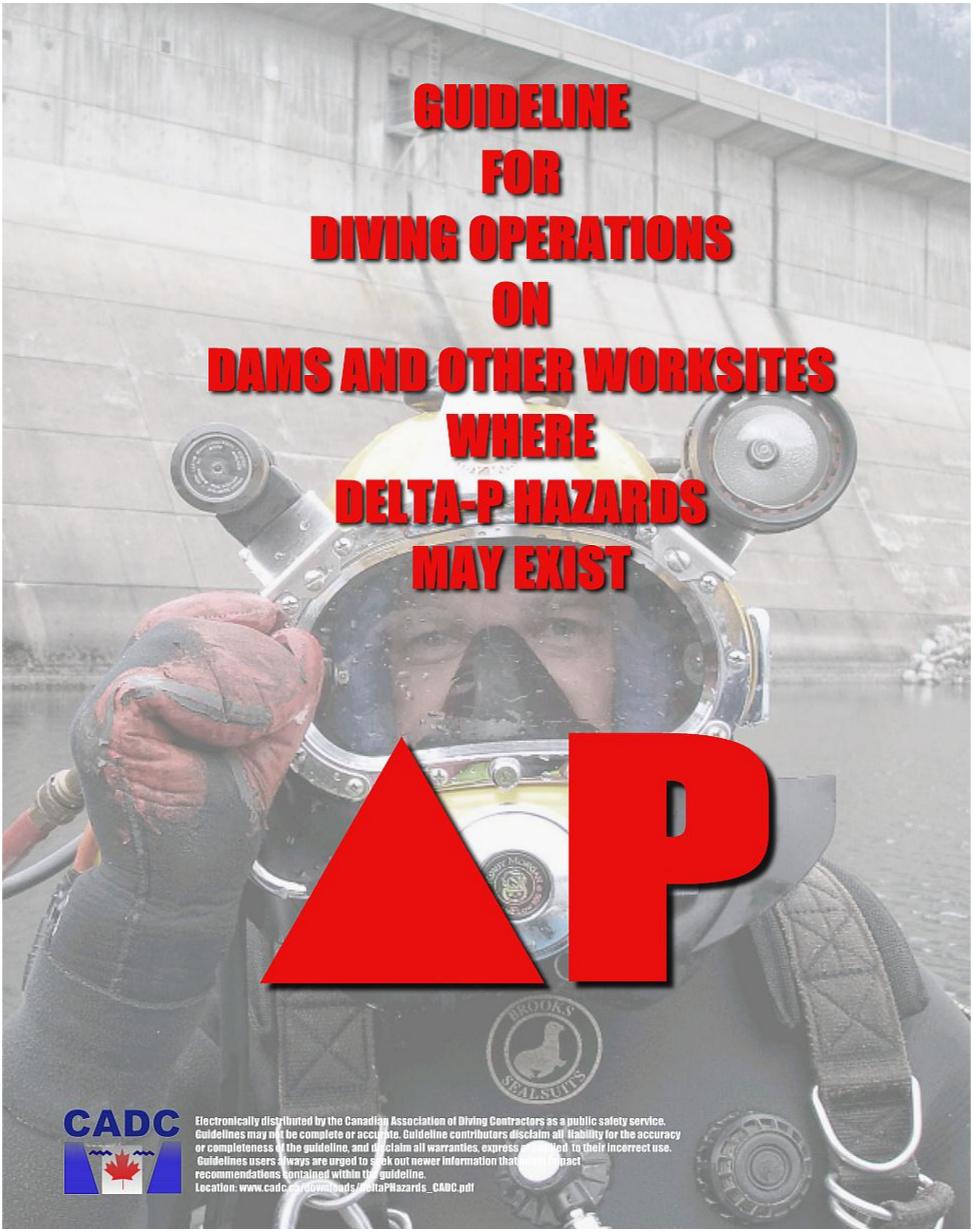
GUIDELINE FOR DIVING OPERATIONS ON DAMS AND OTHER WORKSITES WHERE DELTA-P HAZARDS MAY EXIST



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GUIDELINE OVERVIEW AND PURPOSE

Canadian Occupational Health and Safety statistics reveal that a very high proportion of occupational diving fatalities occur because of divers encounters with differential pressures at dams and other work sites. Furthermore the investigations of these tragic incidents indicate that the majority of these encounters were preventable.

This guideline is primarily intended to assist owners, employers, diving supervisors and divers with a basic understanding of the forces associated with Delta P, methods in detecting Delta P hazards, lock out procedures, selection of appropriate diving equipment and procedures to prevent diver exposure to Delta P forces. In addition, this guideline will also offer some guidance with respect to some limited rescue options, for a diver, from a delta P entrapment.

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Guideline for Diving Operations at dams and other work sites where Delta P hazards may exist.

Introduction

Canadian Occupational Health and Safety statistics reveal that a very high proportion of occupational diving fatalities occur because of divers encounters with differential pressures at dams and other work sites. Furthermore the investigations of these tragic incidents indicate that the majority of these encounters were preventable.

Therefore, this guideline is primarily intended to assist owners, employers, diving supervisors and divers with a basic understanding of the forces associated with Delta P, methods in detecting Delta P hazards, lock out procedures, selection of appropriate diving equipment and procedures to prevent diver exposure to Delta P forces. In addition, this guideline will also offer some guidance with respect to some limited rescue options, for a diver, from a delta P entrapment.

"Delta P (∆P) entrapment should be considered the same as falling from a height, once the fall has started it is usually too late."

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Part 1 – Understanding the basic force of ΔP on a diver

Delta-P: delta normally shown as the Greek triangle "Δ" indicates difference. P is for pressure. ΔP denotes change in pressure. In diving operations delta-p refers to an underwater hazard on or near a water control structure where a difference in pressure exists because of a hole, gap or crack in the structure and in some cases ground faults on the river bed adjacent to a structure. Delta P also occurs at the intake of suction pipes or at any location where there is an unequal pressure difference caused by debris blockage, flange or other device.

In the case of intakes delta P is dependent on the strength of the pump and the depth of the water. The weight of fresh water creates 0.434 pounds per square inch (psi) for every foot (ft) below the surface. Any object including a diver which blocks a hole is held in place by a force equal to the pressure difference multiplied by the area of the hole. See figure 1.

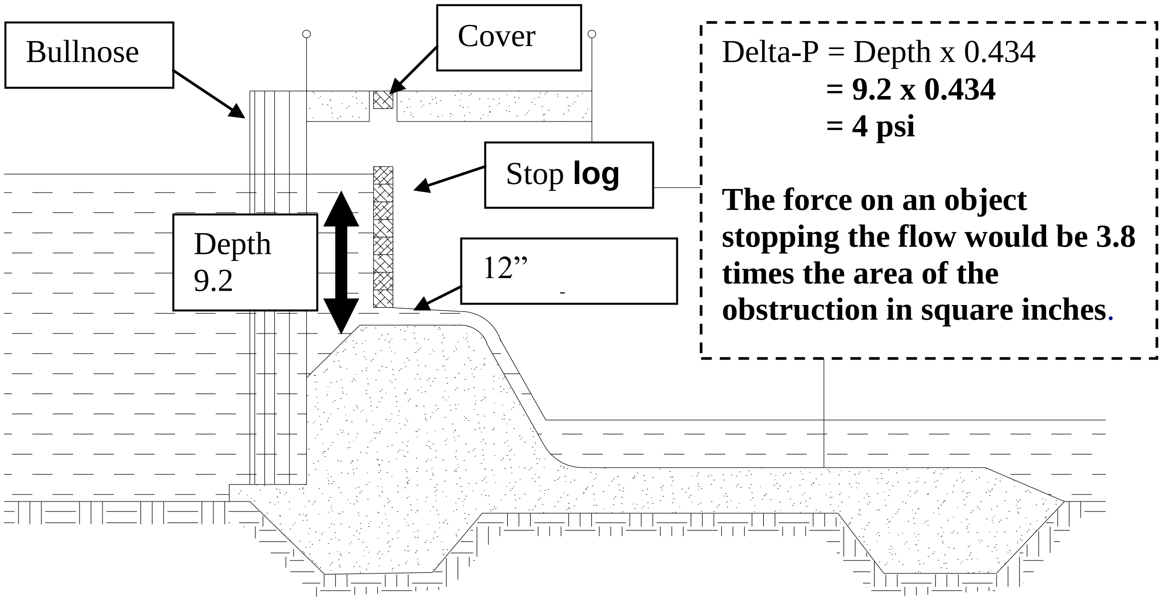


Figure 1: Diagram of an example explaining Delta-P.

The severity of the delta-p hazard is the area of the hole multiplied by the delta-p (change in pressure).

The forces required to pull an object (such as a diver) free from the stop logs are dependent on the following four major factors; the pressure difference across the object, the area of the object subjected to the pressure difference, the water flow rate around the object and the frictional force between the object and the hole in the stop log.

For explanation purposes the pressure difference can be assumed to be 4 psi. The pressure difference is dependent on the density of the water, the depth of the hole and the back pressure of any water continuing to flow around the object.

If the area of the object subjected to the pressure differential is 48 square inches (4 high x 12 inches long) the force would be 192 pounds. If the area is 864 square inches (12 high x 72 inches wide the force would be 3456 pounds (4 x 864).

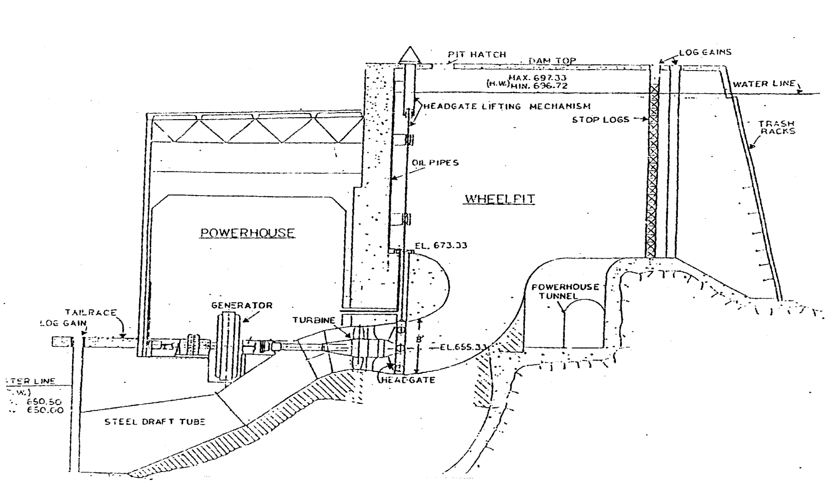
Part 1.1 http://www.youtube.com/watch?v=AEtbFm_CjE0

Part 2 –Dam Nomenclature

http://www.fema.gov/plan/prevent/damfailure/fema148.shtm#2
FEMA glossary

Hydro Electric Dam

Figure 2 & 3 illustrates one example of a hydraulic power dam and head gate. There are many different designs, due to the topography, where the water control structure is not a part of the power house and may be hundreds of meters (or more) apart.



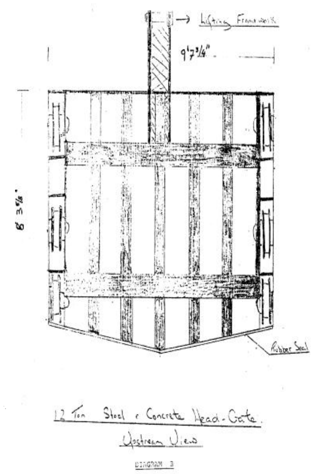


Fig 2 Hydro electric dam

Fig 3 Steel & Concrete Head Gate

Fig 4 is an example of a wicket gate again there are many different designs of water control systems used to regulate a turbine.

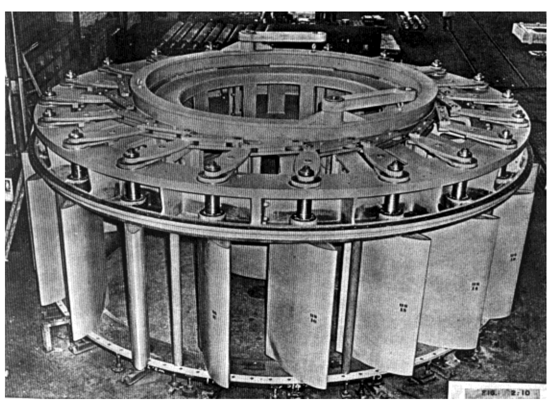
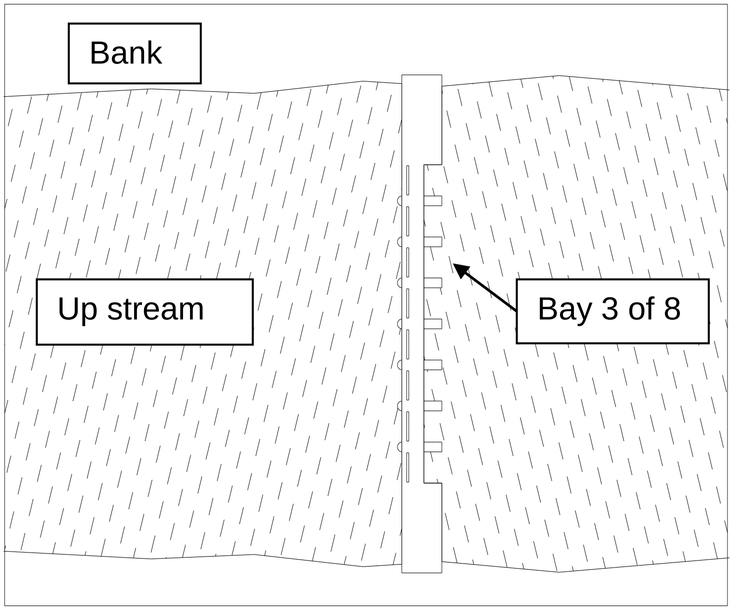


Fig 5 - Birds eye view of a static dam from shore to shore.



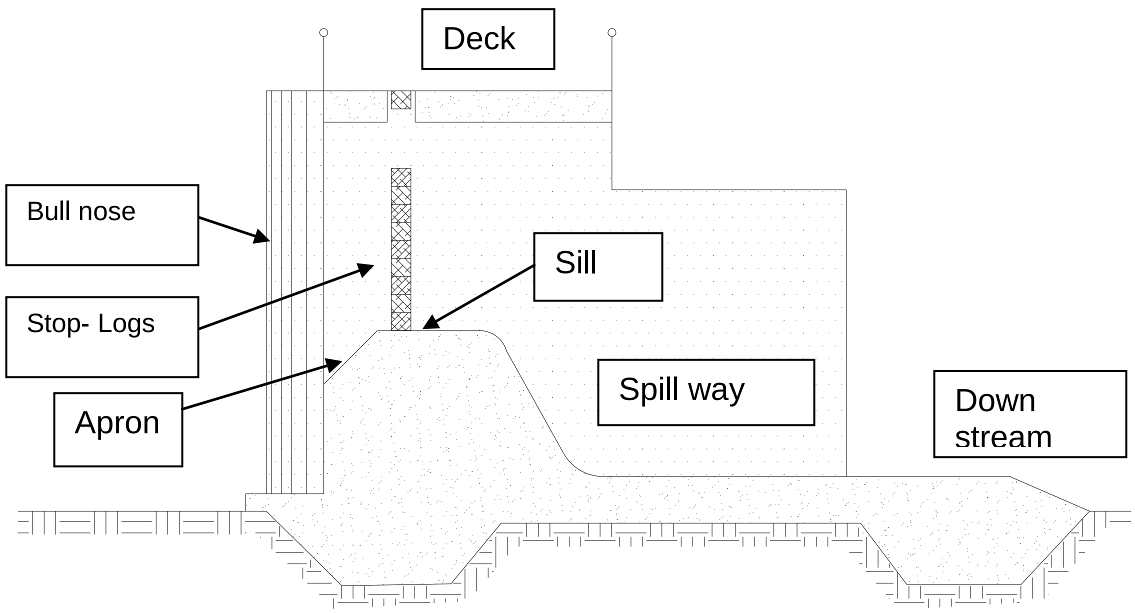


Figure 6 – Profile of a static dam

Part 2.1 – Methods in Detecting Delta P

2.1.1 Visual Signs

One indicator of a potential ∆P hazard is excessive water leakage from the downstream side of a structure. If possible, examine the spillway, stop logs and structure for any visible or audible signs of water leakage and the upstream side of the dam for any signs of suction (vortex), on the surface, before conducting any other surveys. If excessive water leakage is evident then it is imperative that the area around the source of the leakage is surveyed, on the upstream side of the structure, in order to evaluate the severity of ∆P**,** its location and options to either control it or avoid it**.** If additional tests indicate that the source of leakage cannot be controlled then the area around it should be identified as a hazardous area and declared unsafe for diving.

Hydro Electric dams may not always offer good visual indicators because of the design of the structure however downstream boils may be indicative of ground faults or leakage through the structure.

2.1.2 Downstream Approaches

Diving on the downstream side of some types of dams, where turbulence does not pose a hazard to the diver and safe access is available, is worth considering as a safe means of detecting sources of hazardous water flow.

2.1.3 Flow Indicator Devices

2.1.3 (i) Bag Test

A bag test involves the use of a sand bag that is loaded with enough material to make the bag just heavy enough for the circumstances worked in (approximately 3-5lbs). It should be secured to a 3/8” rope that is long enough to reach the entire upstream portion of the structure where the diver will be working plus a control area of at least 5m around the proposed work site. (Note – the rope should not exceed 3/8” diameter because the diver’s feel might be affected it)

It can be a very effective means of detecting ΔP hazards if performed by a person who has had the appropriate training and experience. It will also serve as an effective means of sealing off some ΔP hazards and the rope, if tied off, will assist with the identifying the location of the hazard**.**

In order to be effective, the bag must be lowered and raised slowly across the entire structure at approximately 1 to 2 feet per second and as close as possible to the structure and river bed, (within 10 inches). A vessel should be used to perform the bag test in situations where access to the work site is difficult to reach from the deck of the structure.

A severe draw on the bag and rope or anytime where the bag is trapped and cannot be pulled free are indicators of a serious ΔP hazard; the amount of force to pull the bag free of a ΔP hazard is indicative of the water flow hazard.

Note* The person performing the bag test, must ensure that he is wearing gloves to protect against rope burns and that all persons are free from being entangled by the rope in the case that the bag is caught and pulled through a ΔP source. In addition, the person conducting the test should also be protected by an adequate fall protection Any Significant hazard detected must be effectively controlled before commencing a recognition dive.

Finally, although the bag is an effective means of detecting any existing ΔP hazards it must not in itself be the sole indicator used to declare a site free from hazardous water flows. Its purpose is only to determine if it is safe to commence a recognition dive.

2.1.3 (ii) Mop Test

A mop can be an effective tool to use during a recognition dive because its strands will react to any water flow while the mop handle allows the diver to remain clear of any ΔP hazards. It may be used to verify that ΔP does not exist at a structure that has not shown any indication of hazardous water flow by a bag test. Nonetheless, it must only be used in good visibility and the diver and diving umbilical must be provided with an independent restraint system until the survey confirms the area is free from hazardous water flow hazards. (See - ΔP restraint system)

2.1.3 (iii) Pole & Ribbon Test

It is another means for performing the recognition dive as it allows the diver to remain clear of any hazardous water flows. Nonetheless, it must only be used in circumstances where there is good visibility and the diver and diving umbilical are restrained by an independent restraint system until the survey is completed and the work site is declared safe from hazardous water flows.

2.1.3 (iv) Pole Camera Survey

A pole camera combined with a surveyor's ribbon is useful for detecting gaps and signs of a hazardous water flow in relatively shallow water where there is good visibility. The ribbon is a good indicator of hazardous water flow and may aid in preventing the loss of the camera

The person performing the survey with the pole camera must ensure that all persons are clear of any entanglement with the pole camera system while it is being maneuvered around the structure. In addition, the person performing the survey must use fall protection.

2.1.3 (vi) ROV Survey

In some circumstances a remote controlled vehicle is the only safe means of performing a survey of a dam for potential **ΔP** hazards. Although potentially costly, if the ROV encounters ΔP**,** it is certainly more preferable than a person being injured.

2.2 Recognition Dive

Its purpose is to establish a *safety zone.* This dive is performed in order to identify any signs of a potential ΔP hazard, such as: structural damage, accumulation of debris, cracks, holes and gaps \ after the successful completion of a bag test.

First it is essential that both the diver and diving supervisor review the drawings of the structure with the Dam operator prior to the commencement of a "recognition dive" because of the necessity to familiarize themselves with the structure its dimensions and any service pipes. (Note that drawings are not always a true representation of what may exist, so caution is always recommended.)

Secondly the diver must use a ΔP travel restraint system as per clause 2.5.9 while performing a recognition dive, and finally a rescue plan shall always be written and understood by all persons participating in the diving operation.

2.3 Safety Zone

It is a work site that has been declared safe to dive in after the satisfactory completion of a bag test and recognition dive. The boundaries of the safe zone may be identified by features such as bull noses gates or with other indicators such as chain, rope etc. A 5 m buffer is the minimum boundary when in open water.

Once the safety zone has been established there should be a restraint placed on the umbilical that would prevent the diver from exiting the zone.

2.4 – Lock-Out Procedures

Specific lockout procedures will vary depending on the design of the system to be locked out, the owner's procedures and the water control authority that is responsible for the structures upstream and downstream. In some cases dam operations may be controlled remotely, so clear communications with the water control authority are vital.

For further guidance refer to the CSA Z460 Standard.

2.5 **–** Selection of Diving Equipment & Dive Site

2.5.1 Dive Site {vessel, dam deck or shoreline}

The location and adequacy of the dive site is critical in ensuring that appropriate surface support is provided to a diver while diving at the upstream side of a dam – see clause 8.3.7 of the CSA Z275.2-11 Standard.

The diver's umbilical must be tended directly upstream of the diver and never permitted to enter into any area not checked for delta P, as might be the case if diving from the shoreline or a dive site located at another bay. This is for the reason that the diver's umbilical may be captured by a **ΔP** force and drag the diver into the hazard.

*Note * It is crucial that the divers tender is knowledgeable in the techniques of managing a divers umbilical, the importance of placing restraints on a divers umbilical and the effects of current on a divers umbilical, at dive sites where a* ***ΔP*** *force may exist.*

Another factor to consider when choosing a dive site, at the upstream side of a dam, is the ease of access and egress. Clause 4.4.4 & 4.4.5 of the CSA Z275.2-11 Standard sets out requirements for transportation through water surface and the recovery of an unconscious diver.

2.5.2 Surface Supplied Diving Apparatus

The use of Scuba at water control structures is prohibited, by Clause 7.1.3 of the CSA Z275.2 -

11 Standard.

2.5.3 Thermal Protection

Consideration shall be given to ensuring that the diver is wearing adequate thermal protection for the environmental conditions that the diver is exposed to. This is for the reason that if trapped the diver may die as a result of hypothermia before any rescue is possible.

2.5.4 Quantities of Divers Breathing Mixture

Clause 6.3.1.2 of the CSAZ275.2-11 Standard sets out requirements the general quantity of available compressed air to complete the underwater tasks and for anticipated emergencies. Factors such as, the remoteness of the dive site, the availability of additional compressed air off site and the time to dewater or equalize a **ΔP** hazard (if possible) must be considered as an anticipated emergency while diving at a water control structure.

2.5.5 Umbilical strength members

Clause 8.3.6 of the CSA Z275.2 -11 Standard requires an umbilical strength member to be rated for a minimum breaking strength of at least 2,000 lbs. Nevertheless it should never be used as a means to pull the diver free from a ΔP encounter because of the risk of transferring the load to the diver's air hose and helmet hose connection. (See Diver ΔP Restraint System)

2.5.6 Diver's Harness

Clause 8.3.5 of the CSA Z275.2-11 Standard requires a diver's harness to be a full body harness rated at a minimum breaking strength of 2000lbs for normal diving operations.

Note: A harness with a higher breaking strength may be considered in unusual flow or possible high flow situations.

2.5.7 Diver Communications

Clause 8.3.8 of the CSA Z275.2-11 Standard requires surface supplied divers to use effective two way voice communications. (Round Robin system is preferred)

2.5. 8 TV & Lighting System

The addition of a helmet mounted underwater TV and lighting system is highly recommended for diving operations at dams because it gives the diving supervisor an opportunity to identify any underwater hazards that the diver may not have recognized. It is also provides another means to get the divers attention in the event of communications failure by flashing the light.

2.5.9 Divers ΔP Restraint System

The diver must use a travel restraint system (a separate safety line rated at 5000lbs) while performing a recognition dive because it will assist as a means to resist encounters with a hazardous water flow during descent, time at the bottom and ascent. The system should be designed only as a means to quickly pull the diver and his umbilical clear of any hazardous water flow encountered without compromising the divers air supply.

A separate diver safety line (rated for at least 5000lbs) that is connected to a winch on the surface and fairlead through a clump weight or other substantial rigging system, on the river bed upstream of the work site, is one example of an effective travel restraint system.

Part 2.6 - Rescue Options

2.6.1 Reduction of ΔP

In the event that a diver is trapped by a ΔP force it is unlikely that he will be pulled free, without suffering additional trauma, until the force has been equalized or reduced significantly. Therefore, serious consideration must be given as to how much pressure may be applied without causing serious trauma to a trapped diver. Keep in mind that it is not always possible to reduce the pressure and in those cases prevention is vital because the diver's chances of survival are slim.

Where it is possible to equalize a ΔP force there must be adequate personnel available to operate the equipment necessary for dewatering the work site in a timely manner. In addition, the diver's umbilical should be tended by no more than two persons unless it is necessary to prevent an entrapped diver from being pulled further into a hole or gap.

If the diver is not connected to a travel restraint system then consideration should be given to rigging one to the diver providing that every precaution is taken to protect the standby diver from any hazardous water flow. (A bag test must be performed to verify that the area around the trapped diver is free from sources of ΔP hazards.) Efforts to pull the diver from different angles with the safety line should be attempted during the dewatering phase)

The water control authority is responsible for coordinating the flows of the dams upstream and downstream of the structure where the diver is trapped and every effort should be made to lower or equalize the pressure wherever possible.

2.6.2 Air Injection

The injection of bursts of large volumes of air between an object and source of ΔP**,** in a lab setting, has shown some positive results. However there is no record of it being used in the field to rescue a diver and the volume of air required far exceeds the capacity of the compressors used to supply the diver's breathing air.

Part 3 – Water Intakes

3.1 Intake Design

Water Intake design and flow velocity may vary considerably due to the purpose of the intake. Flow velocity may be low in purpose built intakes for such services as intakes for domestic water supplies and penstocks for power generation, or flow may be high in spillways and in diversion tunnels. Intake design may also require the dive to take place in confined spaces such as; vertical shafts, rectangular vaults and horizontal pipes. Other factors that may influence the dive operation around intakes may include; multiple intakes, depth, visibility and water temperature. It is therefore imperative that the dive operation takes into consideration all of these factors in the planning stages. Due to the nature and inherent hazards associated with diving near water intakes, the location of the diving operation should be considered a ***hazardous location***. See Clause 4.5.3.1 of the CSA Z275.2 -11 Standard.

Always refer to clause 2.2 & 2.5.9 of this guideline while planning a dive at a water intake

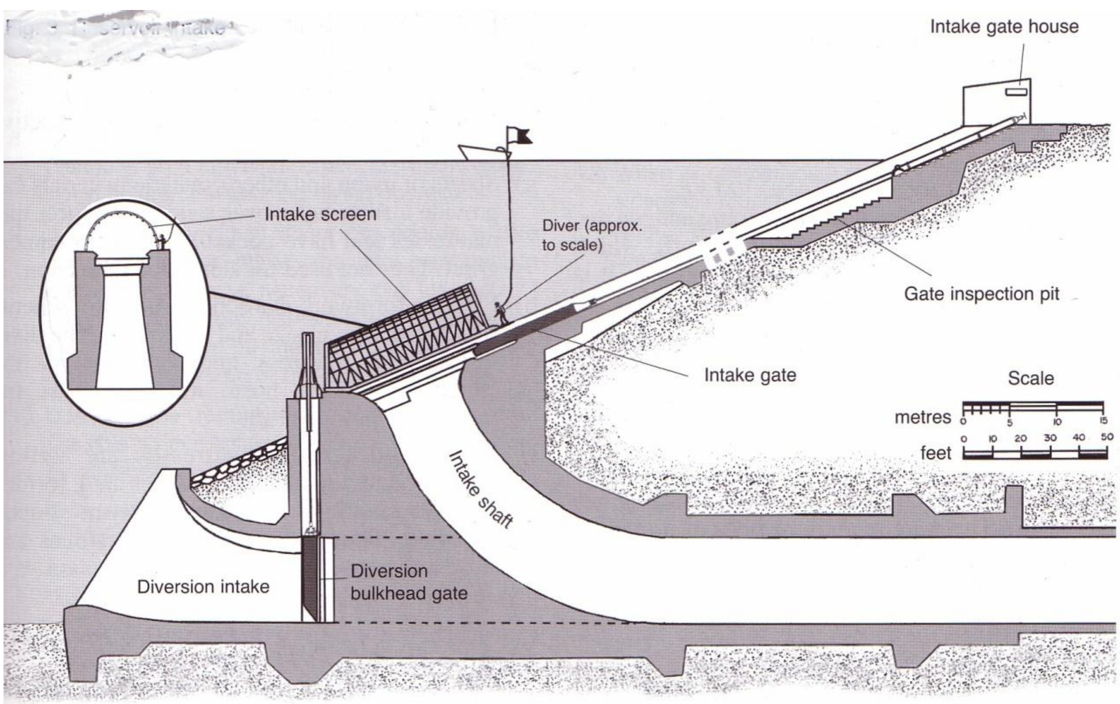


Figure 7 – Reservoir Intake

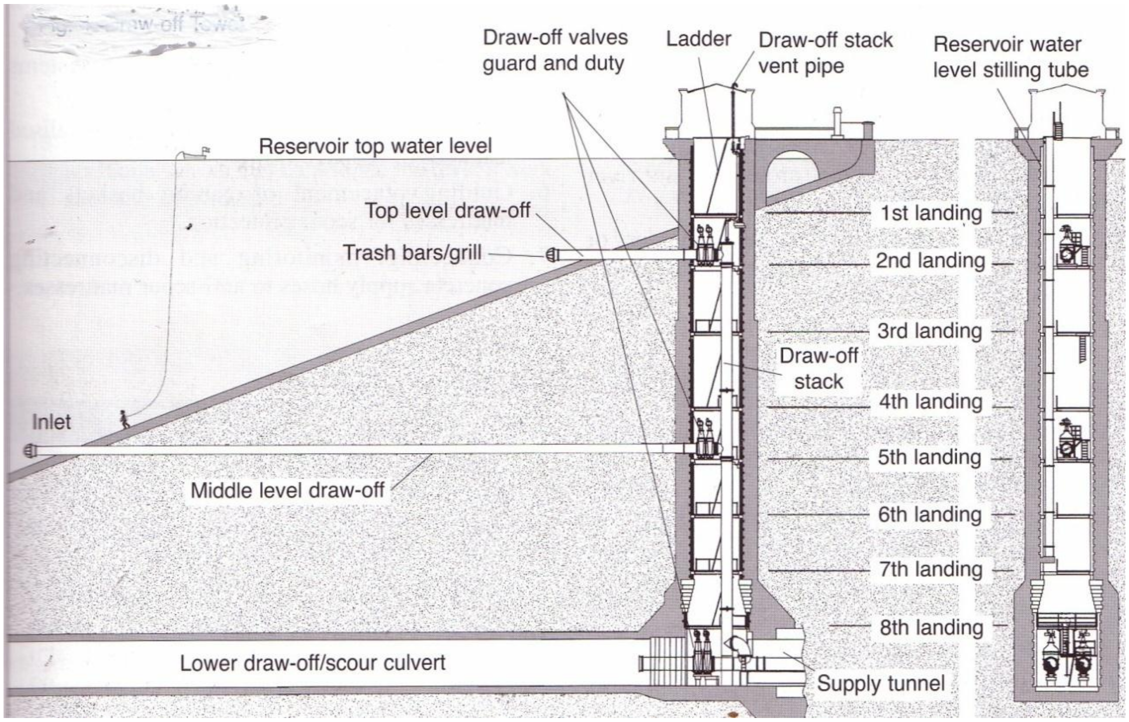


Figure 8 – Draw-off Tower

3.2 Screens

On most intakes a water intake protection system will be installed. There are a number of different types of protective systems used to prevent debris from being drawn into the intake. It is not uncommon for divers to be employed to clean or repair these devices. Listed below are a number of common systems currently used;

Log booms

Are installed on the surface of the water to prevent floating debris from accumulating near the intake.

Fixed Screens

Commonly referred to as “trash racks”, the screens are made up of a number of steel bars or flat stock fabricated to provide a fixed screen over the entrance to the intake to prevent debris from being drawn into the intake.

Traveling Water Screens (TWS)

Traveling water screens are commonly used by power generation companies to protect the intakes. The design of these screens allow for debris to be removed from the screens on a regular automated schedule therefore allowing greater time between manual cleaning of the screens.

Traveling Water Screens (TWS) Safety

When diving on TWS systems, the diver must take caution to ensure that:

- The screen controls are locked-out so that the screen will not start while the diver is in the water.
- Never enter a damaged screen if there is a possibility of a start up.
- Practice good umbilical management, entanglement is of particular concern when working on the TWS.
- Caution should be exercised to prevent hands, feet and extraneous gear from being trapped in machinery if an unexpected start up occurs.

Environmentally Safe Screens

These screens are designed to allow a high flow of water through a large surface area while not impinging on small marine life. Due to the design of these systems the small opening tend to get clogged up and are cleaned by built in high pressure cleaning system, that does not required the use of divers. If maintenance or repairs are required on these systems, divers should be aware of the following precautions;

- Ensure the pump is locked-out
- Ensure flow to the screen has being locked out or controlled to the satisfaction of the diver and diving supervisor

3.3 Water Flow

Ensure that all pumps and valves are locked-out in manner that is acceptable to the diver and diving supervisor. Establish that there is no flow in the intake that the diver will be working near. If the flow is unable to be stopped, ensure it is controlled, in a positive manner, to a rate acceptable to protect the health and safety of the diver, and satisfactory to the diving supervisor and the regulating authority. Clause 4.5.3.4 of the Z275.2-04 Standard.

For further guidance, refer to Part 2.1, sections 2.1.1 to 2.1.3.

3.4 Intake identification

In the event two or more intakes, pipes or ducts are in the same area as the diver, a method will be in place for the diver to accurately and positively identify the intake, pipe or duct he/she is to work on. Clause 4.5.3.3 of the Z275.2-11 Standard.

Caution is to be taken to ensure that other intakes may be in the same area and not identified as part of the same system and therefore may not be identified on site plans, blue prints, etc. i.e.; System 1 - Domestic water supply, system 2 – Fire suppression

3.5 Dive Equipment

Surface supplied diving equipment, c/w voice communications will be used on all dives in hazardous areas as identified in clause 4.5.3.1 and as required in clause 4.5.2 of the CSA Z275.2 -11 Standard.

The use of SCUBA is prohibited when diving operations are carried out near underwater intakes, by Clause 7.1.4 of the CSA Z275.2 -11 Standard.

3.6 Penetration Diving

It may be necessary to enter confined spaces such as pipes, ducts and other structures to perform work in and around intakes. If these dives are to take place additional precautions must be taken to ensure the health and safety of the diver.

For further guidance, please refer to; ***Guidelines for Penetration Diving*** found in Appendix J of the Z275.2-11 Standard.

Part-4 Delta –P hazards working with Pipelines

4.1 Pipeline flooding and pigging operations

Pigging operations and pipeline tie-ins pose a considerable risk to divers if adequate precautions are not put in place to identify Delta-P hazards.
Pipelines are normally deployed in a dry state with a blind flange and some form of double block and bleed, or ball valve assembly to flood the pipe.
Divers have been seriously injured opening valves, or trying to remove blind flanges without verifying equalization in pressure on both sides of the flange.

- Never assume a pipe is fully flooded, always approach flanges with caution.
- Use a removable diffuser or “T” section of pipe on the end of a flood valve to prevent body parts from making a seal on the opening.
- When checking for flow around valves never use your hand, use a frayed piece of rope on a pole or other sacrificial device.
- If available, use an ROV to perform an initial survey before sending the diver in.
- Never stand directly in front of a flood valve when opening, always stand behind or to the side and open valves slowly.
- Never use a Ship’s buoy or other inflatable device inside a pipe when a diver is in the water. Rapid temperature and pressure changes upon submersion can cause buoys to fail suddenly causing a rapid uncontrolled flooding and equalization.

4.2 Protection Flanges used for deployment of Spool pieces and Flexible Hoses

Smaller rigid sections of pipe and flexible hoses are often deployed or "wet stored" sub sea for divers to tie in to existing pipelines and manifolds.
Sealing faces are often protected with a sacrificial plywood face when deployed over the side to the divers. Serious injuries and fatalities have occurred to divers attempting to remove the wooden flanges with small differential pressures behind the flange.

- Always ensure wooden protection flanges have several large holes each end to ensure adequate flooding of the pipe.
- Avoid rapid submersion of pipe sections to allow for flooding before it reaches the diver(s).
- Never try to pry open a wooden flange or "punch" a hole to attempt flooding. Recover the section to surface if possible and drill an adequate equalization hole.

Fig 9 - Example of Diffuser

Fig 10 - Example of a wood flange protection cover that may pose a serious hazard to a diver, because there is no centre hole to equalize pressure differential.

Part 5 – Water Towers/Reservoirs

Part 5.1 – Methods in detecting Delta P forces at dams see: 2.1.3 Flow indicator Devices:

(ii) Mop test
(iii) Pole & Ribbon Test
(iv) ROV surveys

Part 5.2 – Engineering Controls & Calculations

The flow rates on in Water Towers/Reservoirs fluctuate according to the demand on the system and cause an exceptional ΔP hazard without notice. In most cases this water supply cannot be locked out because of public safety issues such as, fire fighting services. For this reason an effective means to protect a diver from a ΔP hazard at the standpipe must be designed and installed (if not already provided) before a recognition dive is performed.

An engineered diffuser that fits over the standpipe on inlet may be one example of an effective engineering control.

<u>Example of calculating excursion umbilical lengths.</u>

a = depth of water

b = distance to nearest hazard from tied-off tending point.

c = maximum length of excursion umbilical to be let out by tender

Note 1: umbilical to be secured at surface.
Note 2: Maximum length of umbilical usually 2-3 meters less than "c" to eliminate contact with hazard. This is an example only, depending on risk assessment and company operating procedures.

E.g.:	**Water depth:**	**"a"**	**10m**
	Distance to nearest hazard:	**"b"**	**25m**

Calculate maximum amount of excursion umbilical. "c" ?

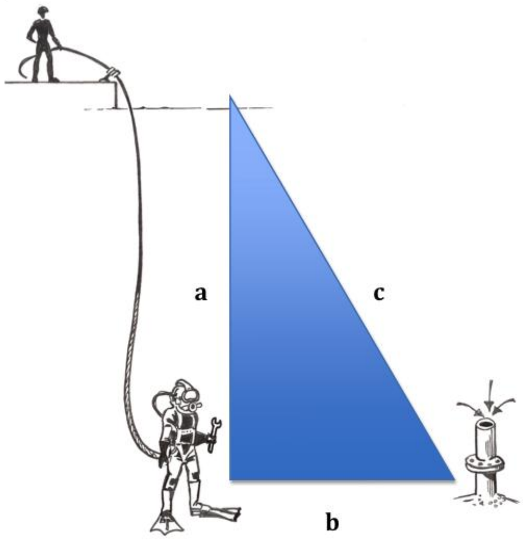
a2 +b2 = c2

(10x10) + (25x25) = c2

100 + 625 = 725 725√ (square root) = 26.9m

minus 3 meters of umbilical, c= 23.9 m

<u>The maximum amount of umbilical to let out by the tender is 23.9m</u>



5.3 Recognition Dive

Its purpose is to establish a safety zone. The dive is to identify any signs of a potential ∆P hazard, such as: structural damage, accumulation of debris, cracks after the successful completion of a flow indicator test.

First, it is essential that both the diver and diving supervisor review the drawings of the Water Towers/Reservoirs prior to the commencement of a "recognition dive" because of the necessity to familiarize themselves with the structure its dimensions and any service pipes.
(Note that drawings are not always a true representation of what may exist, so caution is always recommended.)

Part 5.4 Safety Zone

A work site has been declared safe to dive in after the satisfactory Lock-Out 5.4, and completion of a flow indicating test and recognition dive.

5.4.1 Confined Space considerations

Before a worker is required or permitted to enter a confined space, the employer must meet the requirements of the authority having jurisdiction.

5.4.2 Guard Rails / Fall Restraint

An employer must ensure that a fall protection system is used when work is being done at an elevated place is conducted to the requirements of the authority having jurisdiction.

- Temporary removal of guardrails If a guardrail must be removed to accommodate work,
  (a) Only that portion of the guardrail necessary to allow the work to be done may be removed, and
  (b) Workers exposed to a fall hazard must be protected by another fall protection system when the guardrail is absent.

- The guardrail must be replaced

  (a) When the unguarded area is left unattended, and
  (b) After the work is completed if the circumstances still require guardrails.

5.4.3 Equipment

All safety equipment used in this type of diving must take in to consideration not only diving but as well the possibility of working:

- in confined spaces, and
- at elevated heights.

Note * It is recommended that the dive contractor contact the authority having jurisdiction to establish these requirements.

Part 5.5 – Lock-Out Procedures

Specific lockout procedures will vary depending on the design of the system to be locked out, the owner's procedures and the water control authority that is responsible for the structures.

For further guidance refer to the CSA Z460 Standard.
Part 5.5 – Selection of Diving Equipment & Dive Site

- See 2.5 Selection of Diving Equipment & Dive Site

Part 5.6 - Rescue Options - See 2.6

Part 6 – Ship Intakes – Sea Chests – Propellers - Impellers - Thrusters

6.1 Risk Assessment

6.1.1 Identify Delta P Hazard(s)

Diving contractors must conduct a pre-dive risk assessment to identify known and potential Delta P hazards using appropriate methods of detection. Delta P risks should be presumed to exist in any diving environment where;

- Water levels between adjoining areas vary;
- Water is juxtaposed against gaseous voids;
- Water is mechanically drawn through intakes and
- Water is mechanically drawn toward propulsors, impellers, or other types of thrusters on ships.

Risk assessment methods are closely aligned with proper action by the vessel's engineering department in notifying the diving contractor of active intake pumps, engaged hydraulics (rudders, variable-pitch propellers), and in some instances cathodic protection. Coordination and verification by the ship's engineering department and diving contractor of tag outs and lock outs should follow the initial planning of the operation.

Visual inspections of the work area should only be performed by experienced divers selected by the diving supervisor. Divers conducting the visual inspection can use either the mop, or pole and ribbon test to identify Delta P hazards, when using an independent restraint system and only when the diver has good visibility.

6.1.2 Calculate potential Delta P factors

Where Delta P is known to exist, the **pressure differential** across an opening (or potential opening) through a bulkhead separating bodies of water with different surface levels, or separating a gas filled space at atmospheric pressure from a body of water can be determined by the following formula:

$$\Delta P = D \times P_C$$

Where:

ΔP = Pressure differential across opening
D = Depth of water above opening (or difference in water depth on the two sides of a potential opening
P_C = Pressure change per unit increase in depth

The **total force** (actual or potential) exerted by the pressure differential across an opening is calculated by multiplying the pressure differential by the area of the opening:

$$F = \Delta P \times A = D \times P_C \times A$$

Where:

F = Force in customary units
A = Area in units compatible with units of force

Table 6.1 provides the appropriate constant, P_c for different units of force, depth, and area.

Table 6.1 Constants for use in Calculating Force due to Delta P **$F = D \times A \times P_c$**				
If **F**orce is desired in:	and **D**epth is given in:	and **A**rea is measured in:	Then use the values below for **P_c**	
			for Fresh Water:	for Sea Water:
pounds (lb)	feet (ft)	square inches (in^2)	0.433	0.445
pounds (lb)	feet (ft)	square feet (ft^2)	62.4	64
Newtons (N)	meters (m)	square meters (m^2)	9807	10052
Newtons (N)	meters (m)	square centimeters (cm^2)	0.9807	1.0052
Kilonewtons (KN)	meters (m)	square meters (m^2)	9.807	10.052
Kilograms (Kg)	meters (m)	square meters (m^2)	1000	1025
Kilograms (Kg)	meters (m)	square centimeters (cm^2)	0.1000	0.1025

For operations in brackish water, the values for seawater should be used to calculate Delta P force, unless the pressure increase per foot of water depth can be determined accurately. In waters subject to tidal fluctuations, where the salinity may vary , the values for seawater should be used to calculate the worst case condition.

Delta P hazards near intakes supplying pumps result from potentially high water flow velocities (discussed below), and, if the intake is completely obstructed by a divers body, the maximum suction that could be exerted by the running pump. This suction would be in addition to the pressure head of the water above the intake, at least until the pump stalls or is secured. The suction could persist even after the pump is secured if water cannot be fed into the suction piping to re-pressurize it.

All pumps are rated with a maximum suction head, normally expressed as the height above water level, in feet or meters, that the pump can draw water for subsequent discharge. This is normally referred to as negative suction head. Typical centrifugal and axial flow pumps can function with suction heads of up to 10 feet, although some can operate against suction heads of up to 20 feet. Reciprocating pumps and other types of positive displacement pumps can generate suctions approaching complete vacuum – suction heads for positive displacement pumps are often in the 25 to 29 foot range.

If the suction head, in feet or meters, for the pump is known, the suction force generated if the intake is completely obstructed can be calculated by the formulas given above for calculating delta P force across an opening in a bulkhead. If suction head is expressed in pressure units, such as psi or Pa, then potential suction force is calculated by multiplying the area of the intake opening by the pressure.

Once the pump intake is obstructed, the suction generated by the pump **is in addition to** force exerted by the water depth above the intake.

Pumps installed below water level (such as in ship's machinery spaces, dams, or similar structures) may be designed to operate only with positive suction head – that is, the pump would be incapable of lifting water from a lower level. For such pumps, it should be assumed that if the intake is completely blocked, the pump can lower pressure in the intake piping to atmospheric. This means that the delta P at the intake, and the resulting force, will be due only to the height of water above the intake, as calculated by the formulas given above.

Water flow rate at the intake serving a pump can be taken as equal to the pumps maximum discharge rate – although the pump may sometimes operate at less than full capacity, the maximum rate represents the worst case scenario. Flow rate through an opening in a bulkhead can be determined using the formula:

$$Q = A \times v = A \times \sqrt{2gH}$$

Where:

Q = Flow rate
A = Area of opening
v = Velocity of water flow
g = acceleration due to gravity
H = Depth of water above an opening to a gas filled space, or
= Difference between water level on two sides of a bulkhead.

The flow formula can be re-written as:

$$Q = C \times A \times \sqrt{H}$$

Where:

C = Constant taken from Table 6.2; numerically equal to the product of $\sqrt{2g}$ and any necessary conversion factors, appropriate to the units specified for Q, A, and H
Q = Flow rate in specified units
A = Area of opening in specified units
H = Depth of water above the opening in specified units

Table 6.2 Constants for use in Calculating Flow Through an Opening due to Delta P
Q = Constant x A x √H

If flow **Q** is desired in:	and depth **H** is given in:	and **A**rea is measured in:	Then use the value below for the **C**onstant
cubic meters per second (m^3/s)	meters (m)	square meters (m^2)	4.43
cubic meters per second (m^3/s)	meters (m)	square centimeters (cm^2)	0.000443
cubic feet per second (ft^3/s)	feet (ft)	square feet (ft^2)	8.02

cubic feet per second (ft^3/s)	feet (ft)	square inches (in^2)	0.056
gallons per minute (gpm)	feet (ft)	square feet (ft^2)	3600
gallons per minute (gpm)	feet (ft)	square inches (in^2)	25

Example: Flow rate through a 6 inch diameter circular opening 10 feet below the surface could be calculated by the following:

A = π x r^2 r = 3 in = 3/12 = 0.25 ft
= 3.1416 x 0.25^2
= 0.19635 ft^2
Q = 3600 x A x $\sqrt{H}$
= 3600 x 0.19635 x $\sqrt{10}$
= 2235.3 gpm

Example: Flow rate through a 16 cm diameter circular opening 3 meters below the surface would be calculated by:

A = π x r^2 r = 8 cm = 8/100 = 0.08 m
= 3.1416 x 0.08^2
= 0.0201 m^2
Q = 4.43 x A x $\sqrt{H}$
= 4.43 x 0.0201 x $\sqrt{3}$
= 0.154 m^3/sec

Note: 16 cm is slightly more than 6 inches, and 3 meters is about 9.8 feet. 0.154 m^3/sec is 154 liters per second or 9240 liters per minute. Since one gallon is 3.79 liters, the flow rate through this opening is about 2338 gpm, which is comparable to that through a 6 inch opening at a similar depth.

Differential pressure hazard boundaries can be established by determining the safe flow rate area surrounding the hazard. Divers should avoid areas where the flow velocity exceeds 0.5 meters/sec. (1.64 feet/sec) (.967 knots).

Flow velocity is equal to the flow rate divided by the flow area (v = Q/A). Flow velocity at any distance from the opening can be estimated by assuming that flow coming in towards the comes from all available directions, and that at any distance (radius) the complete flow is evenly distributed over a hemispherical surface with that radius. The surface area of a sphere is $4\pi R^2$; that of a hemisphere is thus $2\pi R^2$. Velocity can thus be calculated:

v = $Q/(2\pi R^2)$

Setting the velocity equal to the maximum acceptable value (0.5 m/sec), the formula can be transposed to calculate the distance where water is moving at that velocity (**stand-off distance**):

v = 0.5 m/sec = $Q/(2 \times \pi \times R^2)$
R^2 = $Q/(2 \times \pi \times 0.5)$ = Q/π
R = $\sqrt{(Q/\pi)}$

Where:

Q = Flow rate, m^3/sec
R = Stand-off distance, m (distance where V drops to 0.5 m/sec)

At any location beyond the calculated stand-off distance, flow velocity will be less than 0.5 m/sec **if the geometry of surrounding structure has been assessed correctly.**

Table 6.3 provides conversion factors to insert into the formula to calculate standoff distance in feet with flow rate input in ft^3/sec or gpm.

Although flow velocities around complex surfaces are not easily calculated, flow velocities and resulting standoff distances, can be calculated for two 2 easily recognized/verifiable deviations from the assumption of unimpeded flow towards an opening in a flat plate:

Case 1: Suction/opening near the junction of 2 bulkheads at right angles

Case 2: Suction/opening near the junction of 3 bulkheads at right angles (like the inside corner of a box)

For case 1 above, at any distance, the flow will pass through half the area that it would for an opening in a flat plate: half of a hemisphere or a quarter-sphere. Surface area will $\frac{1}{4}(4\pi R^2) = \pi R^2$. Standoff distance can be determined:

$$0.5 \text{ m/sec} = Q/(\pi R^2)$$
$$R^2 = Q/(0.5\pi) = 2Q/\pi$$
$$R = \sqrt{(2Q/\pi)}$$
$$= 1.414\sqrt{(Q/\pi)} \approx 1.4\sqrt{(Q/\pi)}$$

For case 2, the flow area is cut in half again - one-eighth sphere. Surface area will be $(1/8)(4\pi R^2) = 0.5\pi R^2$. Following the same analysis as for case 1 will show standoff distance to be $2\sqrt{(Q/\pi)}$

In summary, that for case 1, standoff distance is 1.4 times that calculated for the fundamental (flat plate) case, and for case 2, it is twice as far. These factors hold true for either metric or english units. **Geometry more complicated than the cases described above requires detailed analysis by a competent engineer to determine safe standoff distance**. Table 6.3 summarizes the formulas and factors discussed above.

Table 6.3 Constants for use in Calculating Standoff Distance

$R = \sqrt{Q / (\text{Constant} \times \pi)}$

If Standoff (**R**) is desired in:	and Flow (**Q**) is given in:	Then use the values below for the **C**onstant
meters (m)	cubic meters per second (m^3/s)	1
feet (ft)	cubic feet per second (ft^3/s)	3.28
feet (ft)	gallons per minute (gpm)	1472

Notes:
1. Standoff Distance (R) is that distance at which flow velocity has dropped to 0.5 m/s (1.64 ft/s)
2. For purposes of this calculation, π can be taken as 3.1416
3. Calculation is valid for flow around an opening in a flat or nearly flat bulkhead
4. For openings near the line where **two flat bulkheads** intersect at 90 degrees or nearly so, multiply standoff distance (ft or m) obtained by above formula by **1.4**
5. For openings near the point where **three flat bulkheads** intersect at 90 degrees or nearly so, multiply standoff distance (ft or m) obtained by above formula by **2**

6.2 Risk Management

6.2.1 Elimination of hazard

The safest method of managing Delta P risks is to not to expose a diver(s) to the hazard. Consideration should be given to performing the operation from the surface where feasible. Another option is to use a remotely-operated vehicle (ROV) to perform the operation.

Where the operation must be performed by a diver(s), the focus must be on neutralizing the Delta P before any divers enter the water.

6.2.2 Engineered controls

The preferred method eliminates the Delta P altogether by equalizing the pressure from the low-pressure side of the hazard, either by closing valves or shutting down intake pumps where possible, or by sealing off and flooding a ship's compartment if necessary.

The placement of a physical barrier to isolate the diver from the Delta P hazard is the next-best solution if the Delta P hazard cannot be eliminated. Physical barriers should be placed so as to prevent diver exposure to the hazard, and/or to prevent the formation of a Delta P hazard.

In addition to minimizing differential pressures and isolating divers from Delta P areas, divers who may encounter Delta P hazards should be restrained by an independent harness and tether of sufficient strength to retrieve them from a Delta P situation if necessary. The restraint harness should also limit the diver's movement to avoid encroachment into Delta P areas.

6.2.3 Adherence to safe work practices

Prevention of Delta P situations is essential to maintaining a safe work environment for divers. Proper training, planning, and adherence to safe work procedures must all take place to affect successful operations.

Prior to participating in any diving operations all personnel should receive an appropriate level of training for the specific work they are required to perform. Periodic review of procedures should be undertaken to ensure all personnel are fully competent to perform their work.

Prior to commencing a diving operation divers and support personnel should review the nature of the Delta P hazards that exist and of the methods being used to avoid and control them. Planning and review of an emergency rescue plan by all personnel should be included in the pre-dive review of operations.

Predetermined underwater navigation procedures must be followed when working in the vicinity of Delta P hazards. Planning the divers' route to be followed should include review of ship docking plans and ship shell expansion plans. Potential Delta P hazards can be identified from these plans as well as ship frame spacing and exterior hull landmarks, such as seam welds, that divers can use to navigate along the ship's hull. Only the most experienced and well-trained divers should be assigned to navigate along a ship's hull when Delta P hazards and/or low visibility may exist. Divers and tenders must also take care that the diver's umbilical does not become subject to excess drag from water flow. If the umbilical is captured, then so is the diver. If the drag force is great enough, the diver may be pulled into hazardous areas.

Rendering the work environment safe should include identification and labeling of pertinent pumps, valves, hydraulics, pneumatics, electrical systems and other controls as part of a tag-out/ lock out system. Once identified for lock out, equipment and controls should be physically locked whenever possible and power supplies turned off to prevent accidental activation of equipment or systems. Hydraulic and pneumatic systems require bleeding the pressure off downstream of the point of isolation. There should be one source of authority with control over tag out and lock out.

Where uncertainty about Delta P hazards exists, consideration should be given to deploying a remotely-operated vehicle (ROV) to investigate prior to placing divers in the water.

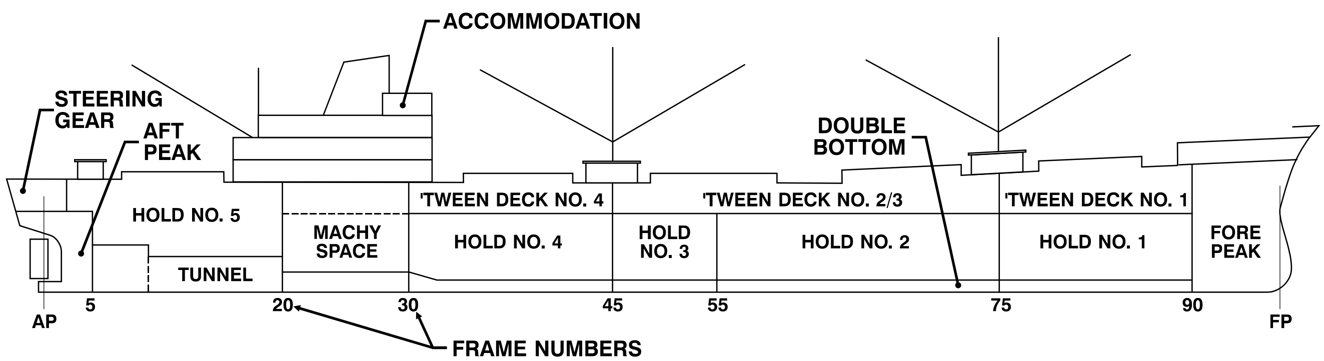
6.2.4 Personal Protective Equipment

Divers should wear a dive suit appropriate for the type of water they will be diving in (uncontaminated/contaminated). Water temperature, depth, and exposure time must also be considered when selecting the proper dive suit.

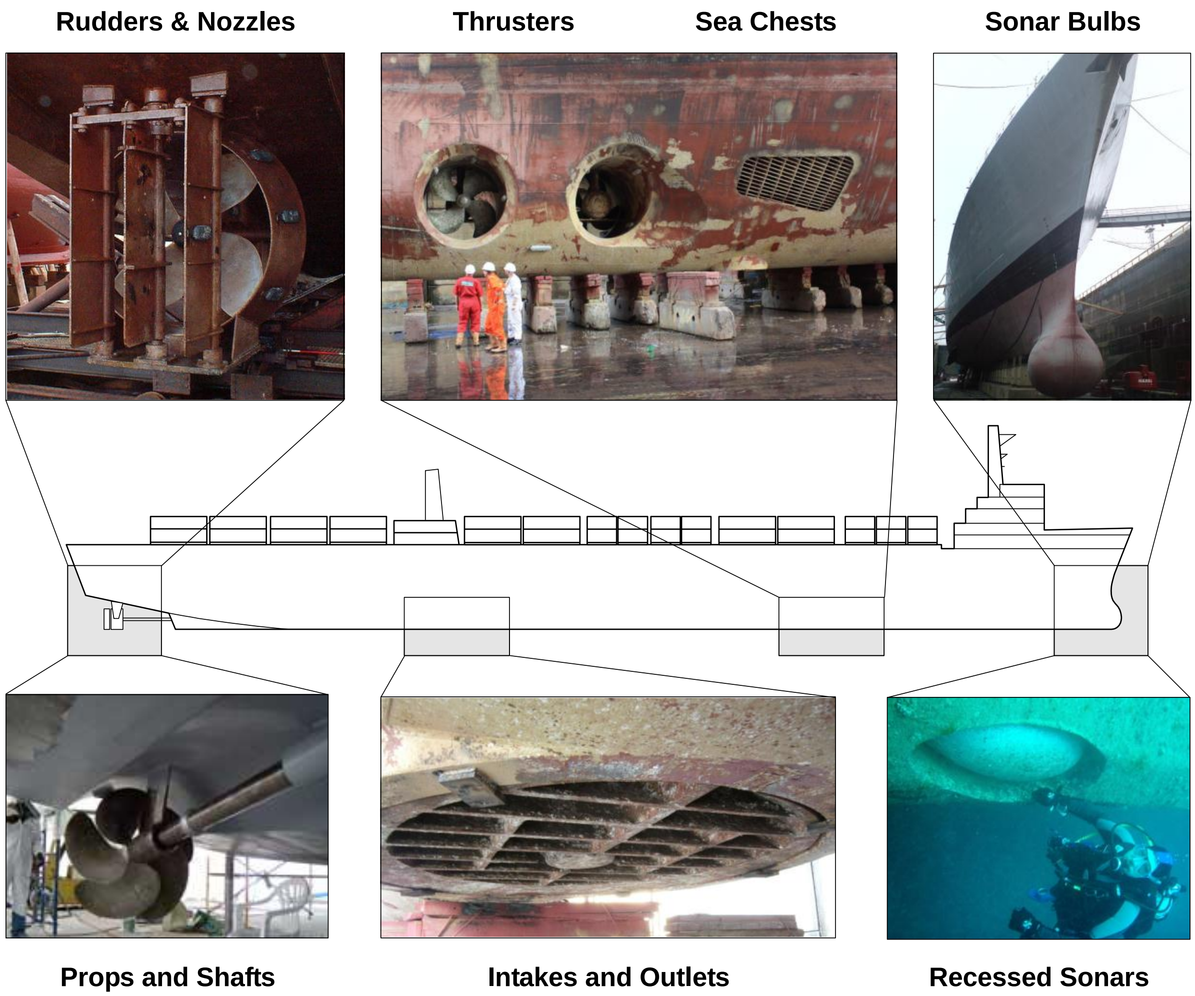
With the possibility of divers being trapped in a Delta P situation and unable to free themselves, it is essential that they use surface-supplied breathing apparatus to ensure sufficient air supply is available until rescue from entrapment can be achieved.

Divers should wear either a full-face mask or helmet with voice-activated communications. Line-pull communications may be compromised in and around areas of Delta P hazards.

Use of an independent restraint harness and tether is necessary where divers may need to be pulled back and away from entrapment in a Delta P situation. This harness and tether should be of sufficient strength to overcome the Delta P force entrapping the diver. Consideration should be given to the amount of force applied to retrieve a diver without causing additional physical trauma in addition to any experienced when entrapped.



General Cargo Ship



Delta P and Other Diving Hazards

SHIP REPAIR SAFETY CHECKLIST FOR DIVING

TAG OUT EQUIPMENT

TAG OUT	SIGNATURE AND RATE
Rudder	________________________
Anchors	________________________
Shaft(s) locked	________________________
Sea suctions	________________________
Sea discharges	________________________
U/W electrical equipment	________________________
Sonars	________________________
Other U/W equipment	________________________

____
(Name of ship)

____
(Signature of Diving Supervisor)