Disaster Survey Report

That occurred during the Great East Japan Earthquake restoration work of the breakwater underwater explosion disaster

Translation and summary by:

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Prologue:

A few days ago, I discovered on the internet an investigation report[1] published by JNIOSH (Japanese National Institute of Occupational Safety and Health Research Institute) recounting an accident in which a commercial diver had died following a cutting accident..
As the quality of this investigation seemed to be very interesting, I chose to translate it and make a summary of it so that other interested divers could take note of it.
Since the original document is in Japanese, I have translated it into 4 different languages in order to be able to summarize it as accurately as possible.
But as it is still an online translation with Google translate, it is not impossible that a few sentences in this document have slight errors.
Please excuse me.

Summary:

In 2011, a tsunami caused a lot of damage in Japan, particularly in a small fishing port on its great east coast where a breakwater had been badly damaged.
In 2012, a diving company was responsible for a number of works, including the underwater cutting of 62 metal piles.
The method chosen by the company was to cut the tubes using thermal electrodes.
As the tubes were sealed in their upper part by a plug of concrete, the company had decided to previously make a ventilation hole in each pile, just under the concrete to avoid the risk of explosion due to a possible accumulation of gases when cutting the tube.
A dozen piles had already been treated in this way without incident, but by starting the cutting of the window on the n ° 13 pile a violent explosion occurred causing the death of the diver.
As a more or less similar accident had already occurred a few years earlier, the JNIOSH decided to conduct an investigation to try to understand the exact cause of this accident and for that it was decided to recreate the circumstances and consequences of the accident by using two small tube models.
This summary outlines the results of this investigation.

Year:

2012

Place:

Fishing port at the Great East Japan?

Diver’s name:

Not said

Diver’s experience:

34 years of commercial diving

Diving company:

Not said

Site depth:

+/- 5, 3 m

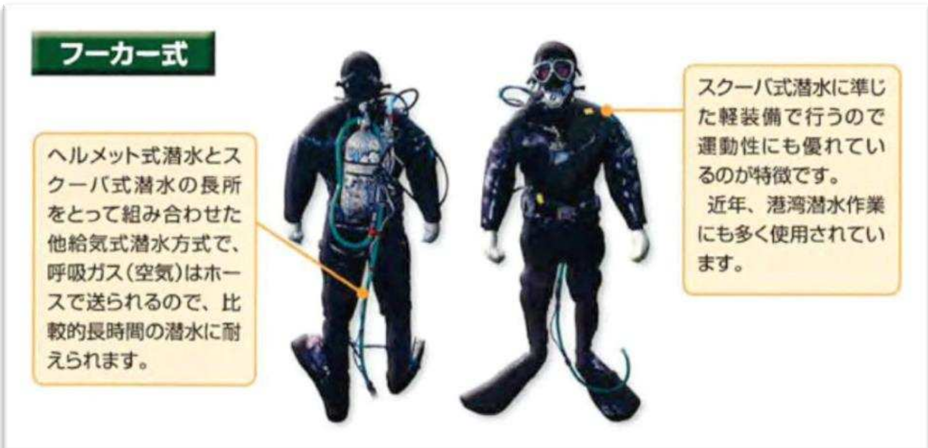
Accident depth:

+/- 2, 3 m

Diving equipment:

Surface demand with band mask and dry suit

Figure n° 1: Type of equipment used by the diver (taken from the document)



<u>Cutting material</u>:

- Oxy-arc cutting torch
- Thermal rods (local conception) Ø 8 mm with 5 steel wires
- Current intensity : 280 Amps
- Oxygen pressure : 6 bars
- Oxygen flow +/- 95 l / min

Photo n° 2: Cutting torch (taken from the document)

Photo n° 3: Type of thermal rod (taken from the document)

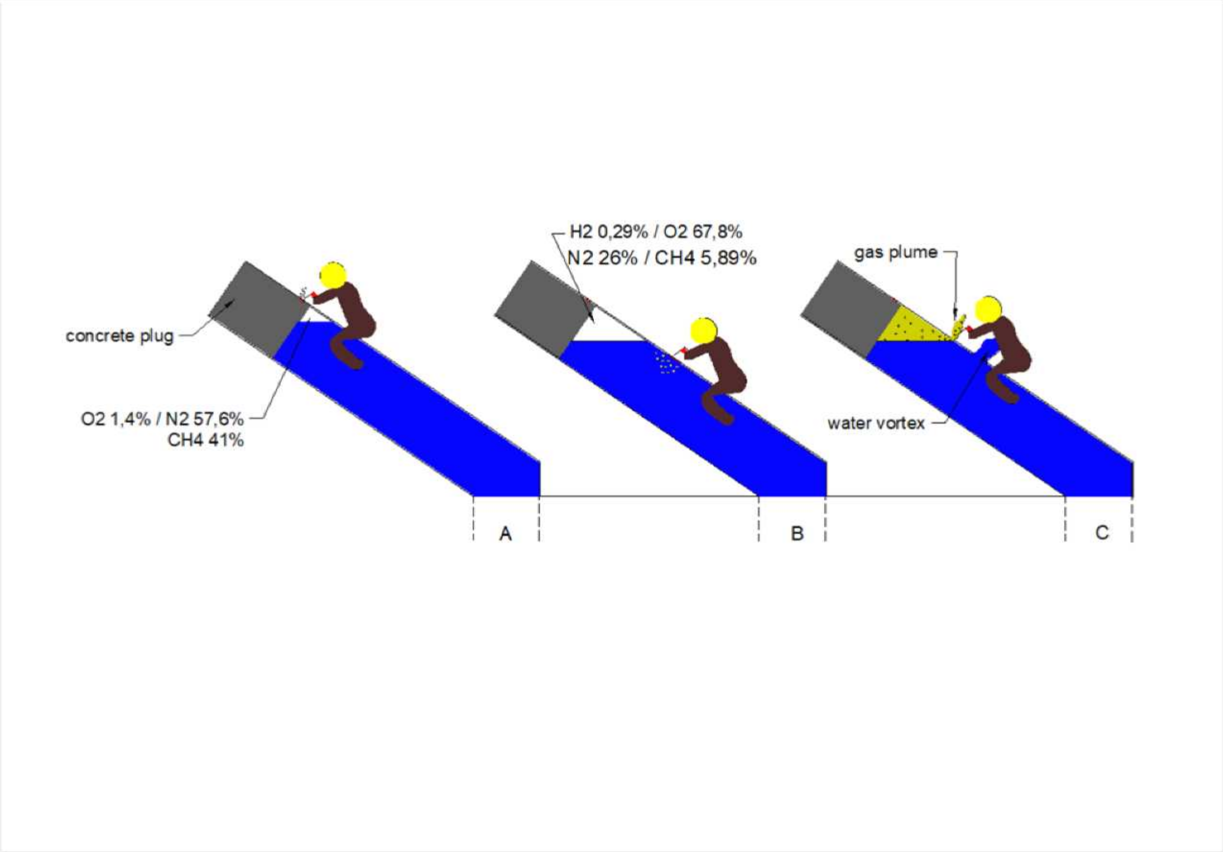
Characteristics of the piles:

- Length 5,1 m up to the cutting level
- Internal Ø 878 mm
- Thickness 20 mm

Description of the accident:

The method chosen for the removal was to cut the tubes at the mud level from the outside using thermal electrodes.
As the top of the tubes were sealed by a certain thickness of concrete, the company decided to make a ventilation hole in each pipe just under the concrete to avoid the risk of explosion due to a possible accumulation of cutting gas.

Figure n° 2: Description of the cutting sequences (illustration FH)



A dozen vertical piles had already been treated in this way without incident; unfortunately it was not the case on the pile n ° 13.
On this pile that had been bend during the tsunami, one (or the) diver had already tried to make a first opening at 98 cm from the top (A), but as it was still in the area containing concrete, a second hole of Ø12, 5 cm was cut at a distance of about 253 cm from the top of the pipe (B).

As this hole was too low to allow proper gas evacuation, the diver began cutting another opening approximately 62 cm above the lower hole.
As the tube was tilted, the diver was straddling the tube having his abdomen at about 50 cm from the lower hole.
Shortly after he started his cut (C), an explosion occurred in the pipe which had for effect to violently compress the surface of the water present in the pipe and project it at high speed through the lower hole where the diver's belly was over.

Due to the intensity of the impact, the diver unfortunately died on the spot.

<u>Accident analysis</u>:

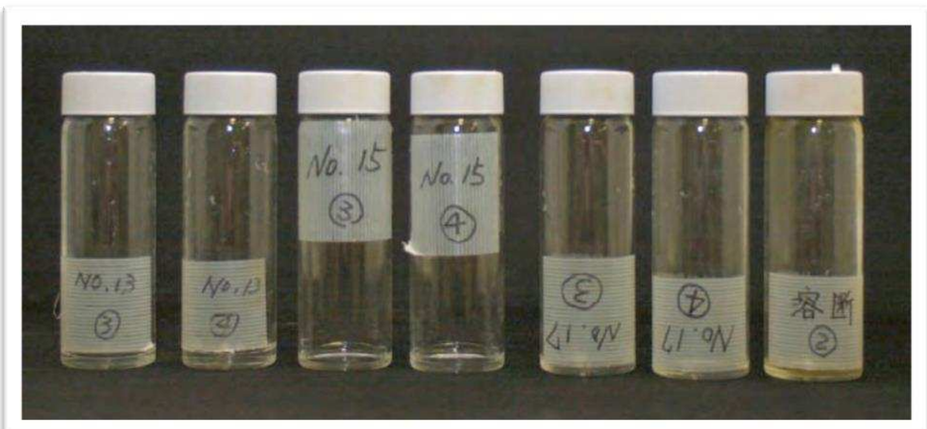
As apparently a more or less similar accident had already occurred a few years earlier, it was decided to conduct a thorough investigation to try to understand the exact cause of this accident and to this end the following steps were undertaken:

- Proceed with the analysis of the residual gases still present in the n° 13 pile.
- Perform the gas analysis of some of the piles that have not yet been perforated.
- Removal of the n°13 pile and analysis of the steel structure.
- Reconstitution of the circumstances and consequences of the accident by using 2 reduced steel tubes.
- Fabrication of a box designed to recover and analyse the cutting gas produced during a series of test cuts.

<u>Analysis of the residual gasses in pile n° 13</u>:

Gas samples were taken from inside the pile prior to its recovery to surface
Based on the investigators' calculations, it was estimated that approximately 94.6 L of residual gas was still in the pile after the explosion.
The samples recovered in pile n° 13 noted that the residual gas still contained the following components:
Hydrogen (H_2), carbon monoxide (CO), methane (CH_4) nitrogen (N_2) and oxygen (O_2) (see proportion in table n° 1).

Photo n° 4: Gas samples (taken from the document)



Gas analysis of some imperforated piles:

Gas samples were also taken from tubes 15 and 17.
In addition to oxygen and nitrogen, they showed a fairly high concentration of methane (see the proportions in table n° 1).

Table n° 1: Analysis results piles 13 - 15 & 17

Sample name	H_2	O_2	N_2	CO	CH_4	CO_2	Total (%)
No.13③	0.00253	64	30.8	0.317	4.91	0	100
No.13④	0	64.4	30.5	0.283	4.83	0	100
No.15③	0	1.41	61.7	0	36.9	0	100
No,15④	0	1.3	61.6	0	37.1	0	100
No.17③	0	1.34	57.6	0	41.1	0	100
No,17④	0	1.4	57.6	0	41	0	100
Blowout ②	0.0557	91.73	6.28	0.432	0	1.51	100

Cutting and removal of pile n° 13:

As soon as the n°13 pile was removed from the water, a steel plate was cut from its lower part in order to take a few pieces for the analysis of the metal structure.
According to the results obtained, the steel composition had no effect on the outbreak of the explosion.

Photo n° 5: Pile n° 13 recovery (take from the document)

Accident reconstitution:

In order to reproduce as closely as possible the circumstances of the accident, two steel tubes at scale 1 / 4.2 and 1 / 8.6 were manufactured.

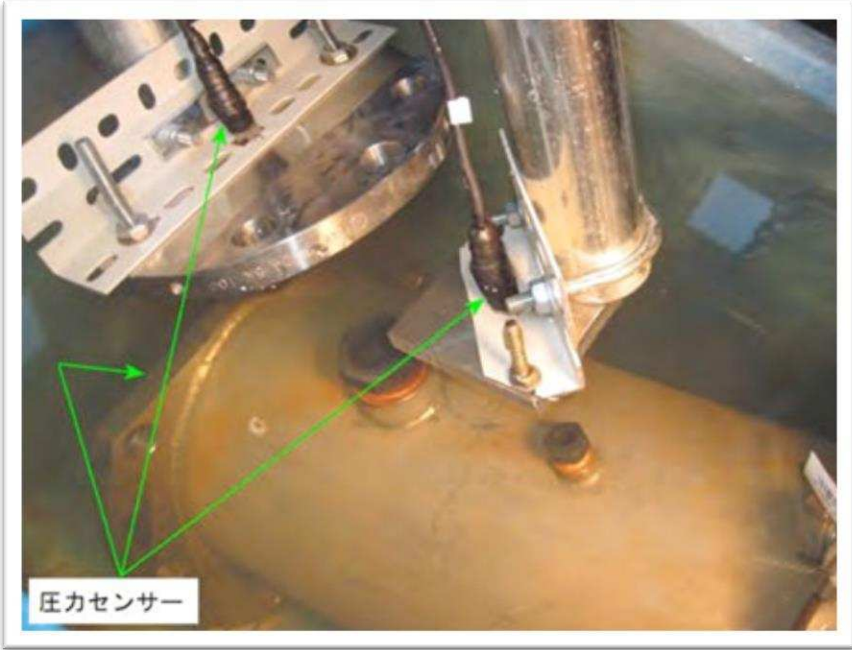
Photo n° 6: Reconstitution tubes (taken from the document)

These were immersed in an experimental basin and filled with a mixture of gases in the following proportions:

H_2: 0.299 %, O_2: 67.8 %, N_2: 26.0 %, CH_4: 5.89 (%).

Photo n° 7: Placement in the experimental basin (taken from the document)

Photo n° 8: Installation of the pressure sensors (taken from the document)



Various pressure sensors were then installed at a clearly defined distance from the two openings.
Finally, to best simulate the consistency and strength of the diver's abdomen, a urethane resin also equipped with a pressure sensor, as well as a thickness of 3 mm neoprene to represent the diving suit were placed in front of the biggest openings.
In addition to these elements, a high speed camera was also used to visualize the effects of explosions.

Photo n° 9: Setting of a probe in the urethane resin (taken from the document)

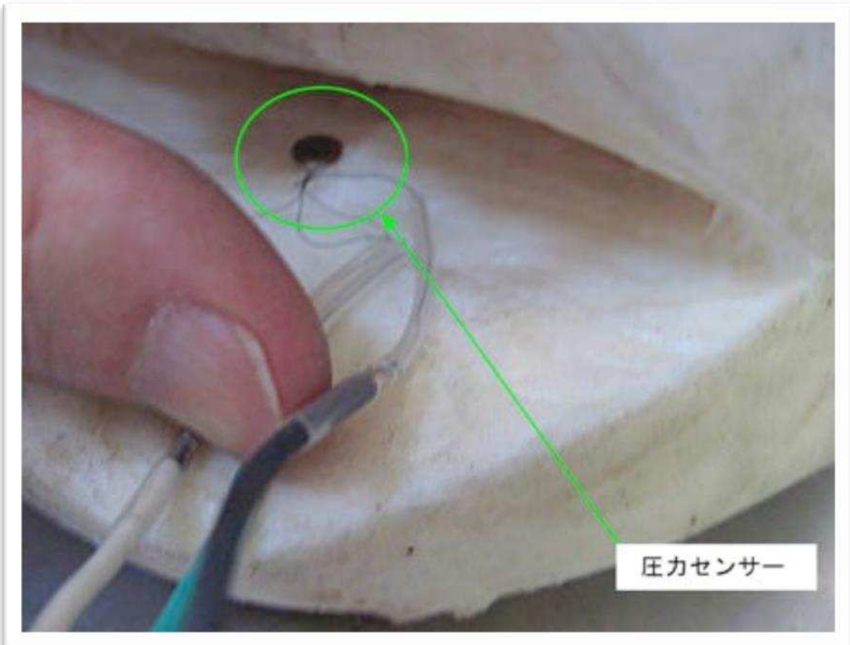
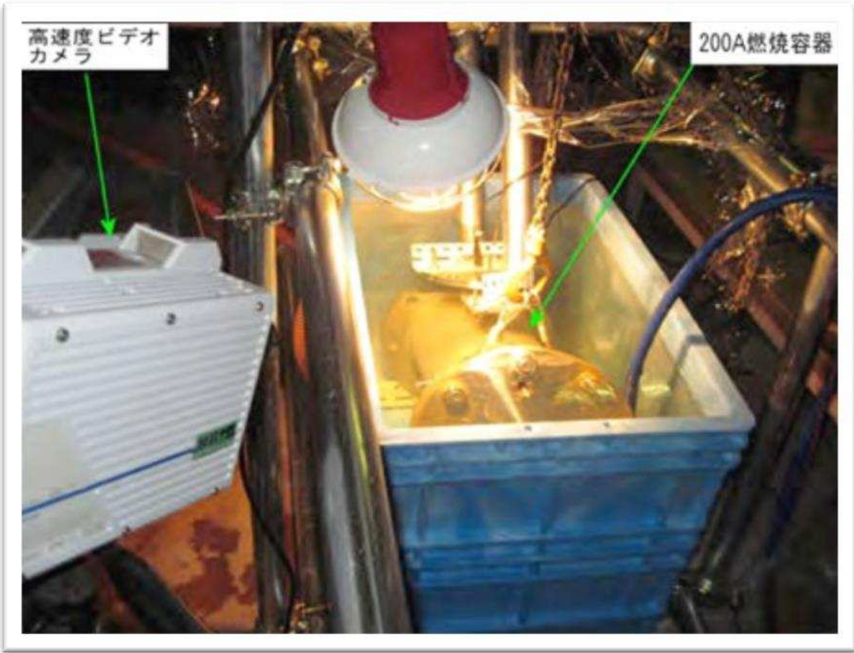


Photo n° 10: Positioning of the urethane and neoprene in front of the hole (taken from the document)

Photo n°11: Positioning of the scaled model (taken from the document)



Results of the reconstitution:

As can be seen from the sequence of the images, at the time of the explosion, the pressurized gas and the water vortex of the lower hole were expelled extremely rapidly from the tube. According to the various recorded measurements, the investigators calculated that due to the hydraulic ram, the diver suffered a pressure shock in his belly of around 737 kPa (7,37 bar), which was sufficient to cause irreversible internal damage.

Photo n° 12 to 15: Effects of the explosion on the small tube (taken from the document)

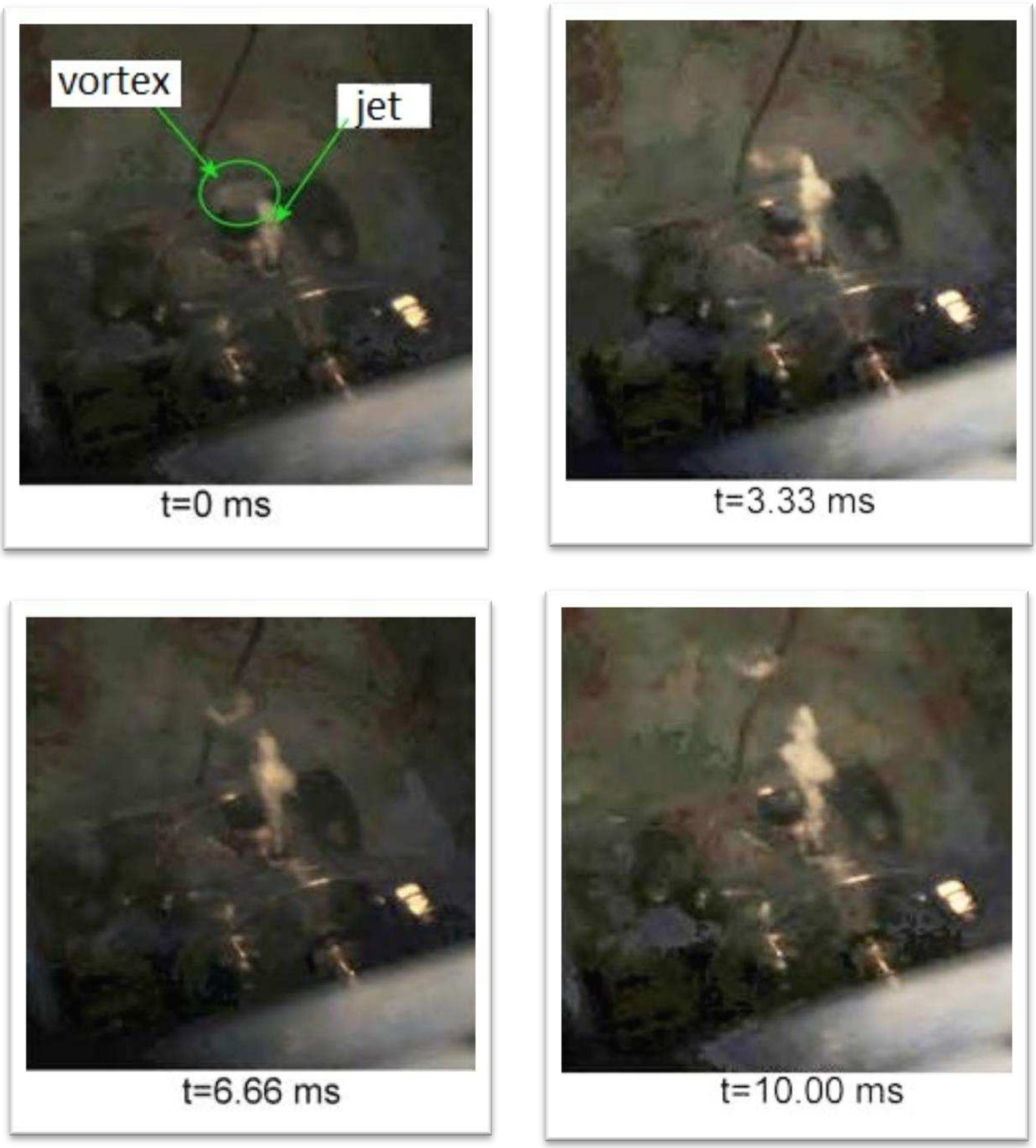
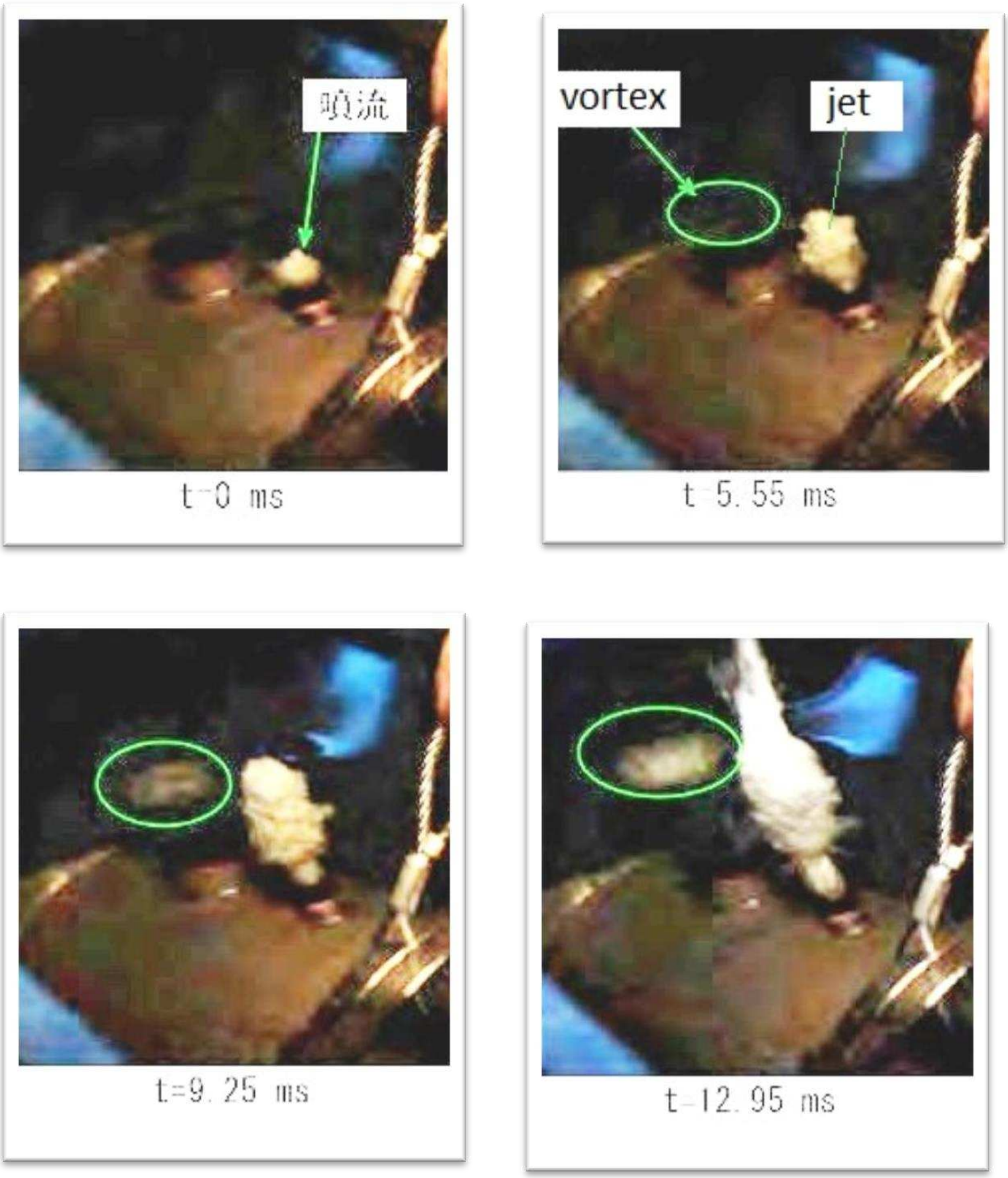


Photo n° 16 to 19: Effects of the explosion on the great tube (taken from the document)



Direct cause of the accident:

This disaster was caused by the formation over the years of methane of geological origin.
By escaping from the silt, this gas then slowly combined with the volume of air also present under the concrete plug until reaching the proportions of an explosive mixture.

Conclusion:

The investigation concluded that in the case of similar work if it is necessary to create a ventilation hole (s) in a confined space, it must be done using a tool that does not generate any sparks.

Additional analyses:

Regardless of the accident reconstitution, the investigators also decided to make a cutting test and analyse the residual gases generated by the combustion of 4 electrodes during the cutting in a steel plate.
To this end a metal box open in its lower part and equipped with acrylic walls onto which 2 steel plates 14 mm thick had been placed was used to recover the cutting gas.
These gases were recovered at the surface via a hose installed at the top of the box, and stored in test flasks.
Two cameras were also placed on the sides of the box in order to be able to visualize how the incandescent slags and the gases at the back side of the steel plate evolved.

Figure n° 3: schematic view of the gas recovery test

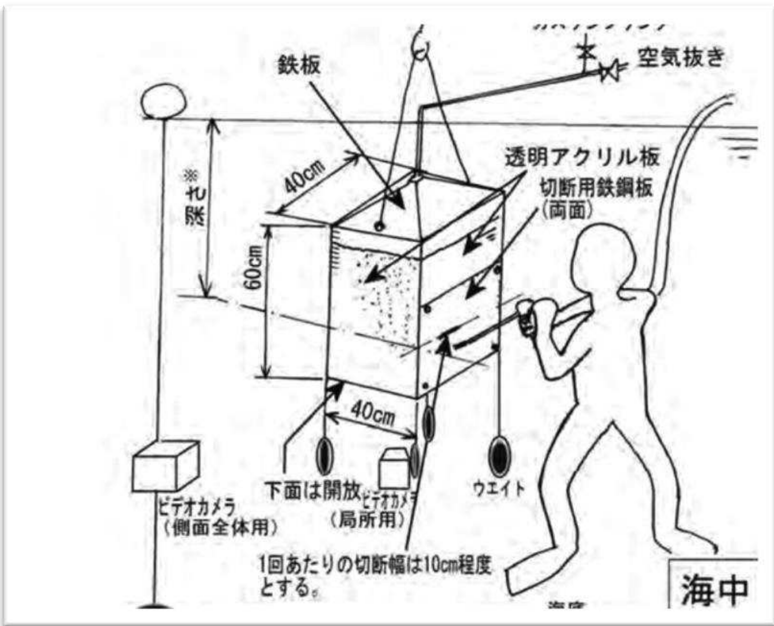


Photo n° 20: View of the gas recovery box

Photo n° 21: View before making it hot

Photo n° 22: View during cutting

Table n° 2: Cutting parameters

Exp. number	Experimental conditions				
	cutting method	Type of rod	Current (Amps)	O_2 pressure (bar)	(L/min)
1	Standard method	Product A	Maximum (280)	6	130
2	〃	〃	〃	〃	140
3	While an arc is generated, Simulate with small disconnection speed. Tilting of the rod (push cut).	〃	〃	〃	140
4	Increase oxygen pressure.	〃	〃	8	130

Table n° 3: Gas analysis results

Experiment n°	Cutting speed (mm/ min)	Gaz volume/rod (L)	Gas flow (L/s)	Gas analysis and composition (vol. %)							
				Gas analysis	H_2	O_2	N_2	CO	CO_2	CxHy	Total (%)
1	208	34.9	1.03	1-1	0.0167	93.5	5.49	0.113	0.855	0	100
				1-2	0.0168	93.1	5.85	0.0989	0.892	0	100
2	300	34.9	1.2	2-1	0.0288	93.4	5.45	0.103	1.06	0	100
				2-2	0.032	92.7	6.34	0.138	0.829	0	100
3	236	22.9	0.763	3-1	0.0464	90.8	7.97	0.166	1.02	0	100
				3-2	0.0427	90.2	8.79	0.159	0.841	0	100
4	450	22.9	0.964	4-1	0.0384	91.3	6.71	0.18	1.82	0	100
				4-2	0.0491	91.3	6.59	0.182	1.83	0	100

Personal remarks:

1 ° Regarding the death of the Japanese diver, we can see that in this case, he did not die because of the shock wave generated by the deflagration (or detonation) of the explosive mixture that has travel at high speed in the water, but well because of the hydraulic water hammer which was generated by the rapid expansion of the gas pocket confined in the tube.
As every time we cut or create an opening (kerf, hole) in a plate, we realize that the risk of hydraulic ram exists.
It is therefore not useless to remember that whatever the technique used (pushing or pulling the electrode), it is necessary at all costs to avoid facing the cut, but rather stay ahead of it to be protected from any accidental pressure jet.

2 ° Looking at the analysis results in Table n° 3, it can be seen that the gases produced during the cutting test contain hydrogen (H_2) and carbon monoxide (CO), that is to say two flammable gases and therefore likely to explode.
On the other hand, what is quite challenging is that in the present case, the percentage of these two gases is well below their lower explosive limit (LEL) with oxygen (3.9% for H_2 and 12.5% for CO) and therefore these gas residues could not have exploded, even if they had been confined.
One could therefore wonder if the figures mentioned in the table are correct because during our cutting jobs we have almost all already suffered the inconvenience of such explosions and many divers have lost their lives because of them.
To my knowledge, only two analyses of this type have been published on the net.
This one, together with an analysis conducted by NEDU[2] in 2003, in which the percentage of hydrogen and carbon monoxide was also much lower (0.5% H_2) (0.2% CO) than the L.E.L of these gases.
Comparing the results of the table, it would seem that the percentage of hydrogen increases according to certain cutting parameters such as the volume of steel cut per second, which in other words means that the thicker the cut, the more explosive gas is produced.
As is known, under water the production of hydrogen (it is the one that concerns us the most) is generated in very small quantities by the electrolysis of sea water and by the cracking of water molecules due to the intense heat emitted during cutting.
One thing that seems certain now, is that even if these two analyses have errors, it is unlikely that the hydrogen generated during any cutting reaches the 70 – 90 % announced by some.

Pursuing this line of thought on the low proportion of hydrogen encountered in these two analysis, one might even wonder whether the majority of accidents involving underwater explosions (other than those involving gas burning torches) were not due to the presence of another explosive gas, as it was the case here in this accident in Japan.
The only way to find out would obviously be to do some additional analysis.

Perhaps the few cutting specialists still actually working could try to convince the concerned bodies that are: IMCA, ADCI, HSE, IOGP and others, to do this type of analysis.
This could only be beneficial for our entire community.

In the meantime, let's continue to pretend that hydrogen is the main cause of the explosions and continue scrupulously to apply all the necessary safety rules when cutting under water.

DIVE SAFE

Reference:

[1] https://www.jniosh.johas.go.jp/publication/pdf/saigai_houkoku_2016_06.pdf

[2] https://apps.dtic.mil/dtic/tr/fulltext/u2/a442691.pdf