

1889

Compressed Air - its
Physiological and pathological effects.

By

James Hunter

M B & C M - 1878 -

Preface

The cause of any want of completeness which may be judged to characterize some of the observations embodied in the following pages, will be intelligible to those who have a practical acquaintance with the Work which afforded the opportunity of this study, and who can appreciate therefore, the difficulties which, as a Consulting Practitioner, I experienced in prosecuting such an Enquiry.

- The inaccessible position of the working Chambers of the Carissons, the fact that the workmen were foreigners speaking a different language, & having prejudices against being made the subjects of scientific observations; the constant noise of machinery, & my other professional duties only leaving Night as the time available for this special work; - these, taken with the interruption caused by an outbreak of small-pox in my practice, were some of the difficulties I encountered.

Yours Truly,
April 25, 1887

Introduction

Introduction

Opportunities of studying the effects of compressed air on the human framework have been infrequent, because under natural conditions of depression, such as exist near the Caspian and Dead Seas, its results are unappreciable; and again because in mines, where the degree of increased pressure may be considerable, its effects are obscured by the altered composition of the atmosphere.

It is only therefore in such processes as diving, working at the preparations for the founding of piers in deep water, and in establishments where the use of compressed air is had recourse to as a remedial agent, that its effects on the healthy and diseased body respectively, may be studied.

In the belief, that one of the main improvements in the Therapeutics of the future, will consist in the application of

Compressed air to the treatment of ailments in which experience and Experiment shall have proved its use to be of remedial value I have resolved that my Thesis ~~shall~~^{shall} be, an account of some of the symptoms which came under my observation in men engaged at the founding of the deep water piers of the Forth Bridge.

And though, happily in a sense, it is not part of my duty to chronicle serious accident, or loss of life; yet opportunity sufficient to compare the leading features produced, with those noted in similar undertakings elsewhere, was frequently presented.

Rarefied air, such as is experienced in ascending high mountains, and in balloon ascents, produces, like compressed air, certain bodily disturbances to a limited extent compatible with life.

Rarefied Air

Mal des
Montagnes

The condition known as Mal-des-Montagnes, being first observed at an Altitude about 1700 feet above the Eternal snow line.

The train of symptoms induced both by compressed and by rarefied air, is due to their influence on the blood system.

In the one case, namely, to the tendency to complete saturation of the Oxyhaemoglobin of the arterial blood with Oxygen, and in the other to the diminution of the amount of available Oxygen for the requisite saturation of the arterial blood Oxyhaemoglobin. And this latter barometric de-oxygenation has such an influence, that, though in healthy people at moderate heights the poverty of Oxygen is not manifestly appreciable; yet when such people are the subjects of disease the Anaemic type is readily noticed.

Respiration of
Attenuated Air

Respiration of attenuated air has also been recommended and tried for the treatment of certain affections, and more than fifty years ago methods for making its application practicable had been used by Lunna, Jourdanet, and others; whilst residence in altitudes where rarefied air could be naturally inspired, has been frequently and extensively adopted, with marked success, in the treatment of Phthisis.

Effects of
Compressed Air
on Divers

It happened, strangely enough, about the time the Forth Bridge piers to which reference has been made were being constructed, that I had opportunity of witnessing the effects of compressed air as experienced by Divers.

A diver had gone down to inspect the moorings of the Forth Guard-ship, and, owing it was supposed,

to his life, and other lines having become fouled among the moorings, was lost, in about forty fathoms of strong-current water.

The day following another diver attempted to descend, to ascertain accurately the cause of the previous day's disaster.

When about half way down, he felt himself quite unable to guide his movements, the strong currents existing whirled him round and round; and he signalled to be brought to the surface which he reached in a very exhausted condition.

Some minutes afterwards when I saw him he was gasping for breath, his lips were blue, his face livid, and his pulse small, rapid, and feeble.

Around the neck there existed extensive extravasation of blood into the cellular and other tissues, forming a powerful mechanical

Symptoms
noted in case
of Diver

impediment to respiration, and probably acting also on the respiratory Centre in the brain.

This case which I saw for a short time on transit to Her Majesty's Ship Sultan, was recalled to my remembrance by the appearance of a case which has since occurred in my practice, - the case namely of a Child who was suffering and evidently recovering from Morbilli, and in whom there suddenly developed subcutaneous Emphysema, which was so extensive as actually to induce a fatal issue.

The compressed air in the case of the Diver referred^d, or more probably, the decompression on his being brought rapidly to the surface, led apparently to rupture of minute bloodvessels, whose contents extravasated into the area already indicated.

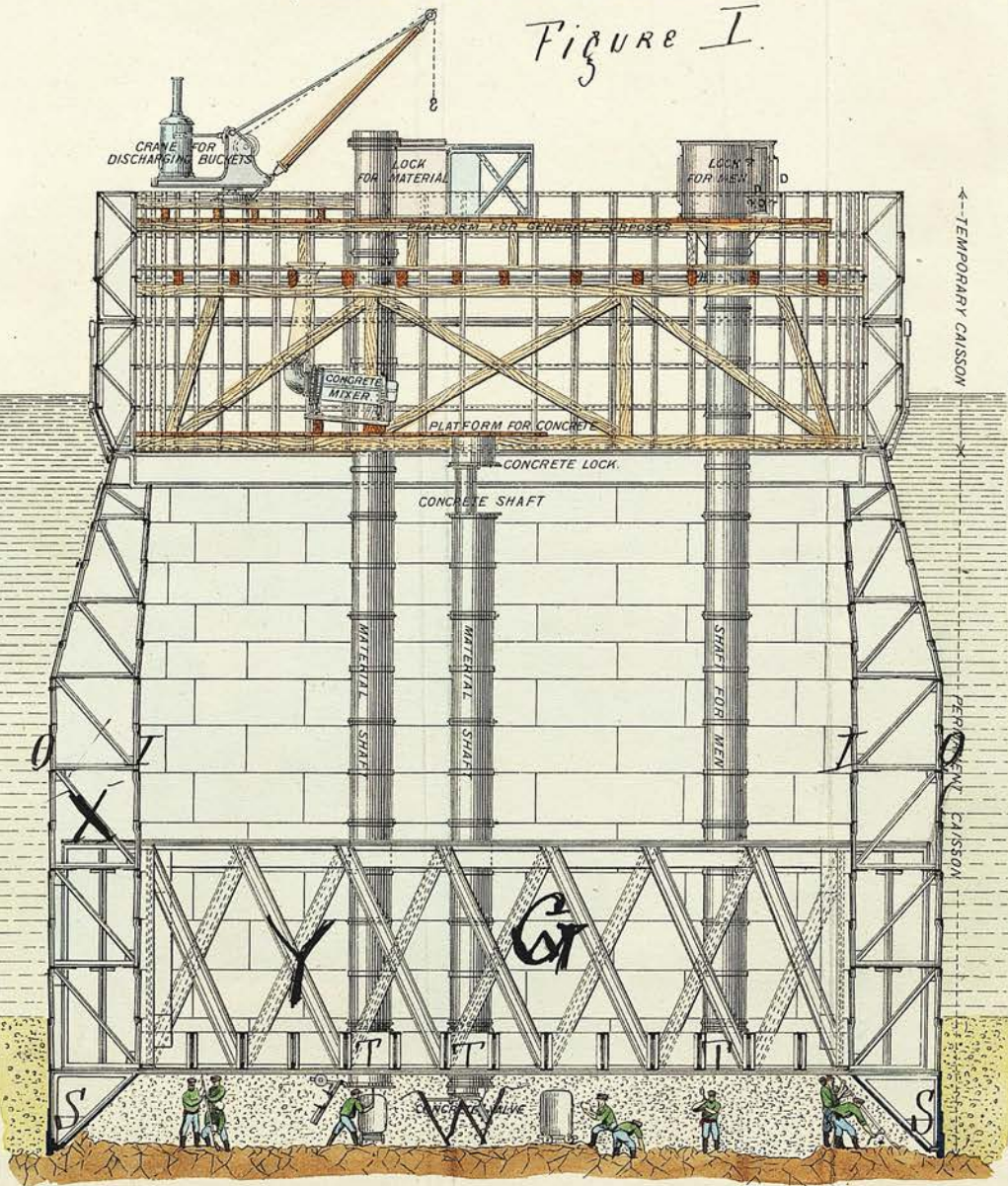
In localities where divers are employed in the pursuit of an industry, means are adopted whereby a comparatively slow return to the pressure of the ordinary atmosphere is secured, and even then the mortality reaches, as in the instance of the Isare Divers of the Greek Archipelago, as high as ten percent.

Mortality
amongst

Divers of
Greek
Archipelago

FORTH BRIDGE.
QUEENSFERRY SOUTH WEST CAISSON.

Figure I.



This and the other Engineering plans accompanying this Thesis, I owe to the kindness of Mr. A. V. Biggart, C. E., Forth Bridge Works.

It will be needful to describe shortly the construction of a Caisson, in order to understand aright the conditions of possible work by means of it.

A caisson is essentially a cyl.
*inder, devised for carrying out submarine Engineering work through the instrumentality of compressed air.

It may vary indefinitely in regard to size.

The idea of a caisson originated so long ago as the year 1647.

Since that date it has been improved in various ways according to the experience gained from undertakings in which it has been employed, until now it may be regarded as being in many respects perfect.

A Forth Bridge caisson (Figs I. II. & III.) is a huge Cylinder having a general appearance not dissimilar to that of a Gasometer.

A Caisson

The diameter of one of the caissons at its base is 70 feet, & at the top 60 feet. The height is about 70 feet but varying ^{ies} according to the depth to which it was required to be sunk.

Structurally a caisson (Fig I) may be regarded as consisting of three portions.

- (a) An Outer (O) and (b) an Inner (I) shell of strong iron plates, and
- (c) A Working Chamber (W)

Structure
of a Caisson

The Working Chamber forms the lower part of the caisson, and is bounded laterally, by the Outer Shell, and superiorly, by an Air-tight roof, from which the Inner shell takes origin and is continued to the top of the Caisson.

The roof of the Working Chamber is securely rivetted to cross-girders (G), which form a groundwork for the

FORTH BRIDGE.

AIR LOCK FOR MEN.

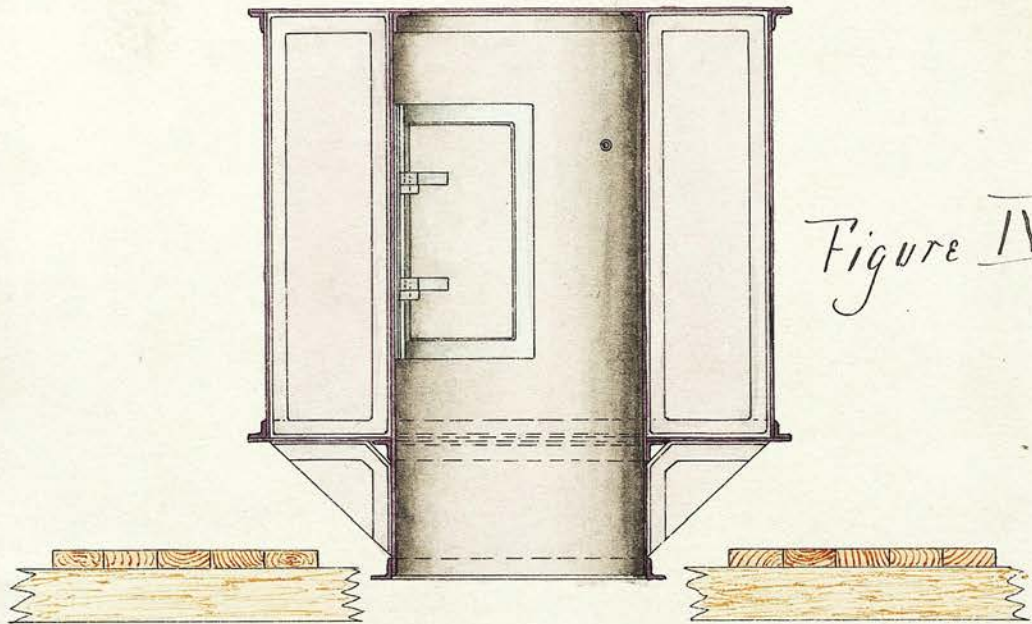
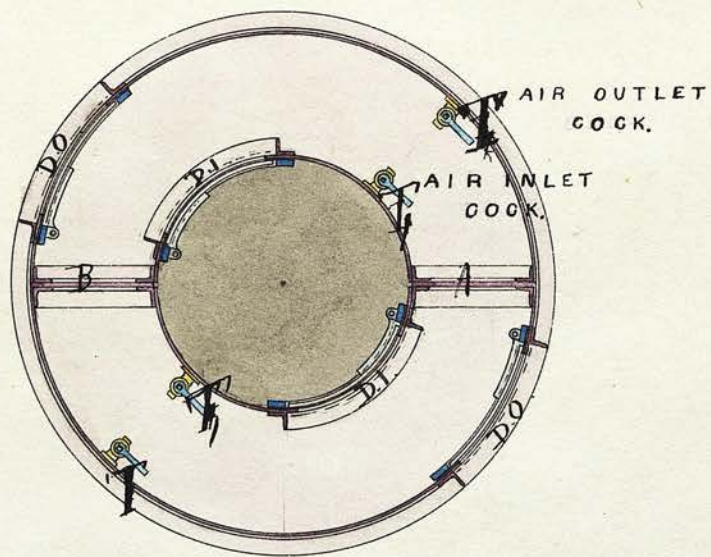


Figure IV



Construction of the Caisson.

The lower or cutting edge of the shell forming the wall of the Chamber, constitutes what is known as the shoe of the Caisson (S).

Opening into the Chamber through its roof are three tubes or shafts (T), each three and a half feet in diameter.

Two ~~being~~^{are} for the outlet of the excavated material, and the third for the ingress and egress of workmen.

These shafts are continued from the working chamber below, to the top of the Caisson, where they ^{are} secured at a convenient level to the working platform.

On the summit of each shaft is fixed an Airlock.

With the air-lock used by the men the construction of which is different from that of the

material locks, I shall only, in description deal.

It (Fig IV) consists of a double iron cylinder, - the inner and longer of the two corresponding to the size of the air shaft on the top of which it rests, & the outer which is double the diameter of the inner, & is separated from it at the base by an enclosed floor.

A single plate forms the roof of both cylinders.

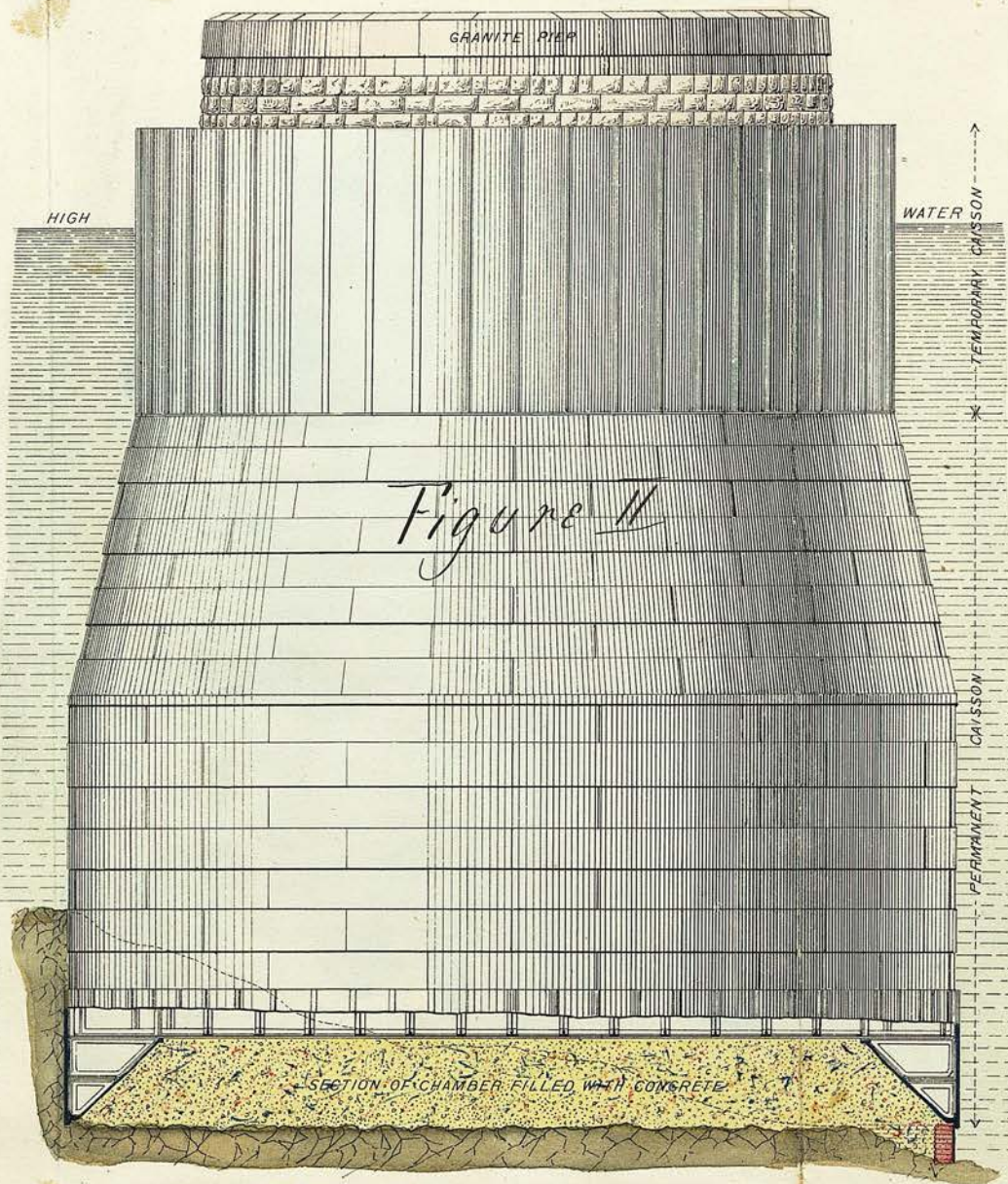
The space between the two cylinders is divided by two upright iron diaphragms (A & B seen on section) into two distinct compartments.

Each compartment having a strong iron door in the outer cylinder (D.O.) communicating with the outer atmosphere, and another similar door opposite in the inner cylinder (D.I.) opening into the air shaft.

An Air lock

Its Structure

FORTH BRIDGE.
INCHGARVIE SOUTH WEST CAISSON.



In the roof of each compartment is a small bull's eye light, and also two small tubes with stop-cocks ($T+T_1$), one for admitting air (compressed) from the air shaft with which to equalize the pressure in the air lock with that of the working Chamber, & the other for the escape from the lock of the compressed air in order to admit ~~the~~ return to the outer world.

When the construction of a Caisson had been completed and it had been safely launched and towed into the position where it was desired to found a pier, the part of the Caisson above the roof the working Chamber, (Y Fig I) and between the outer and inner shells, (Fig IX) was gradually loaded with concrete, until the Caisson rested firmly on the mud, and could not be moved therefrom either by the

influence of the rising tide, or by the pumping into the Chamber of compressed air for service in the process of excavation.

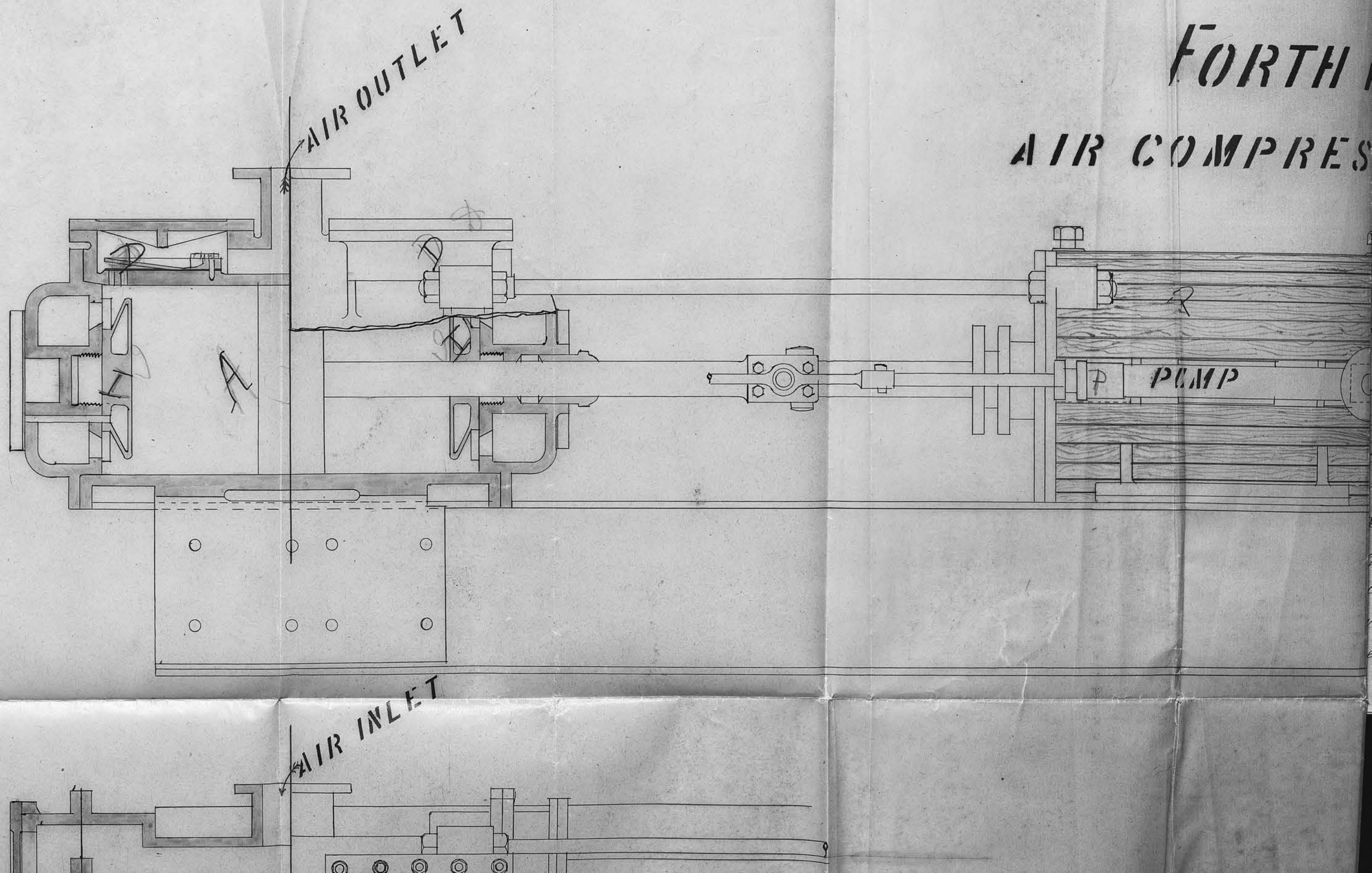
Caissons
resting on
rock

Tro of the Caissons (Fig II) did not rest on mud but on the edge of an irregular ledge of rock, which had to be cut away until a level base was reached for the floor of the Caisson.

In these cases the real Engineering use of compressed air in repelling the surrounding sea was easily observed, for the least fall in the requisite air pressure was at once indicated by an equivalent rise of water within the working-chamber.

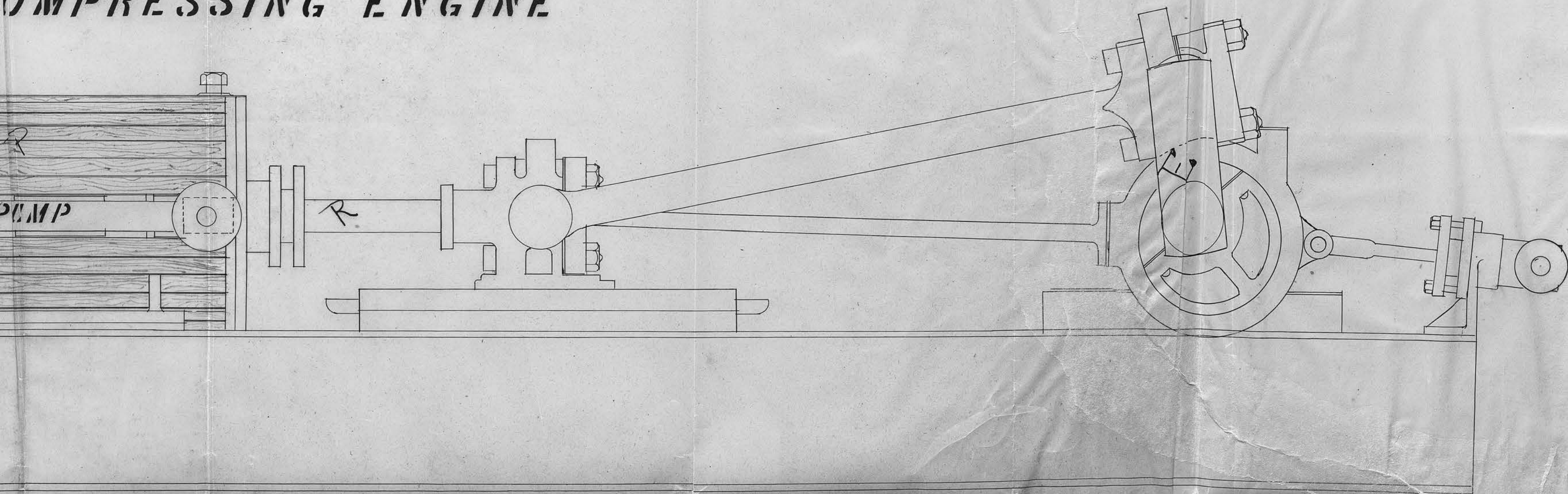
In these Caissons, ^{also} there was permitted the opportunity for a free exchange of vitiated atmosphere than was possible in Caissons embedded in mud. The air vitiation produced at

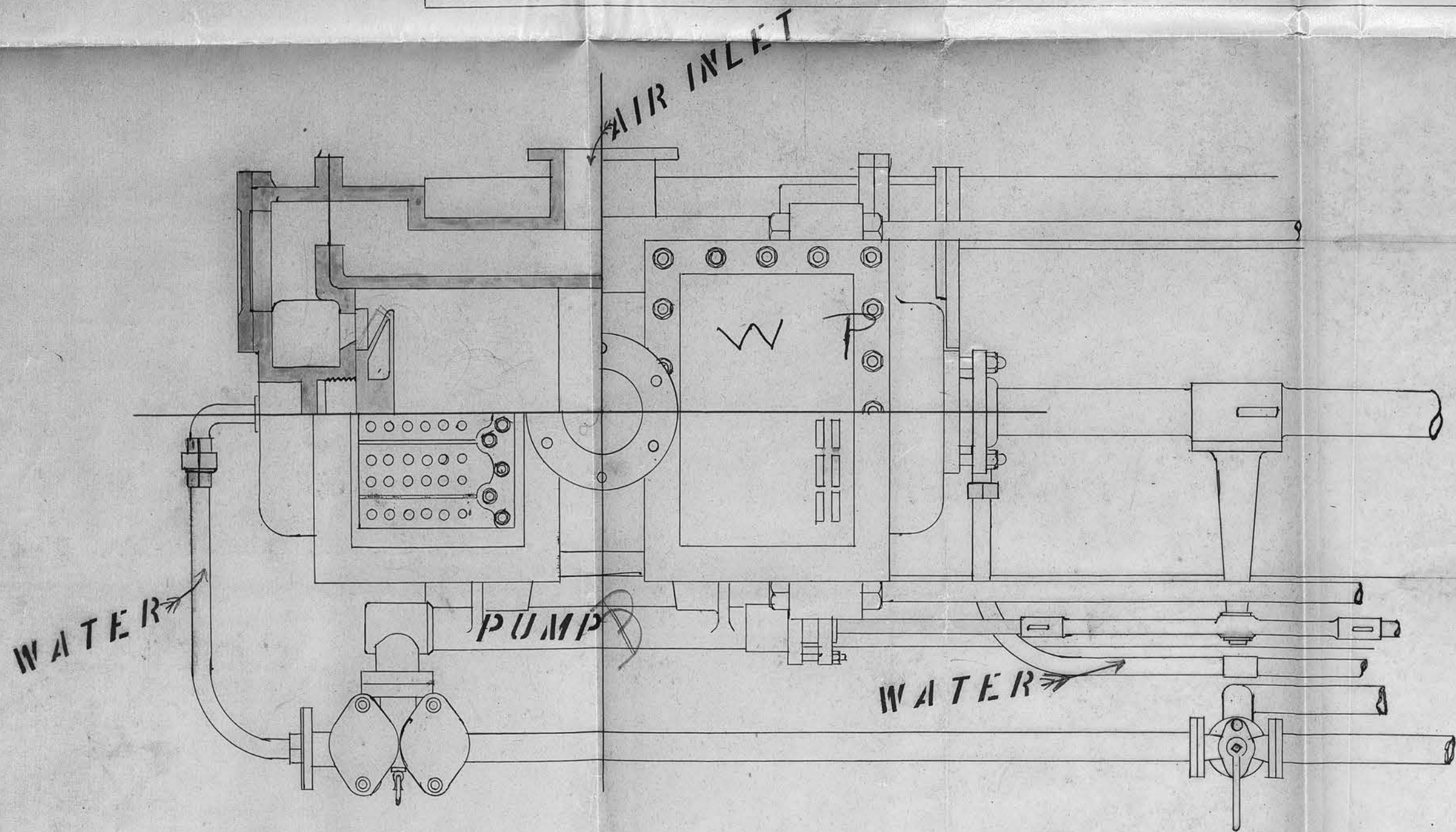
FORTH AIR COMPRESS



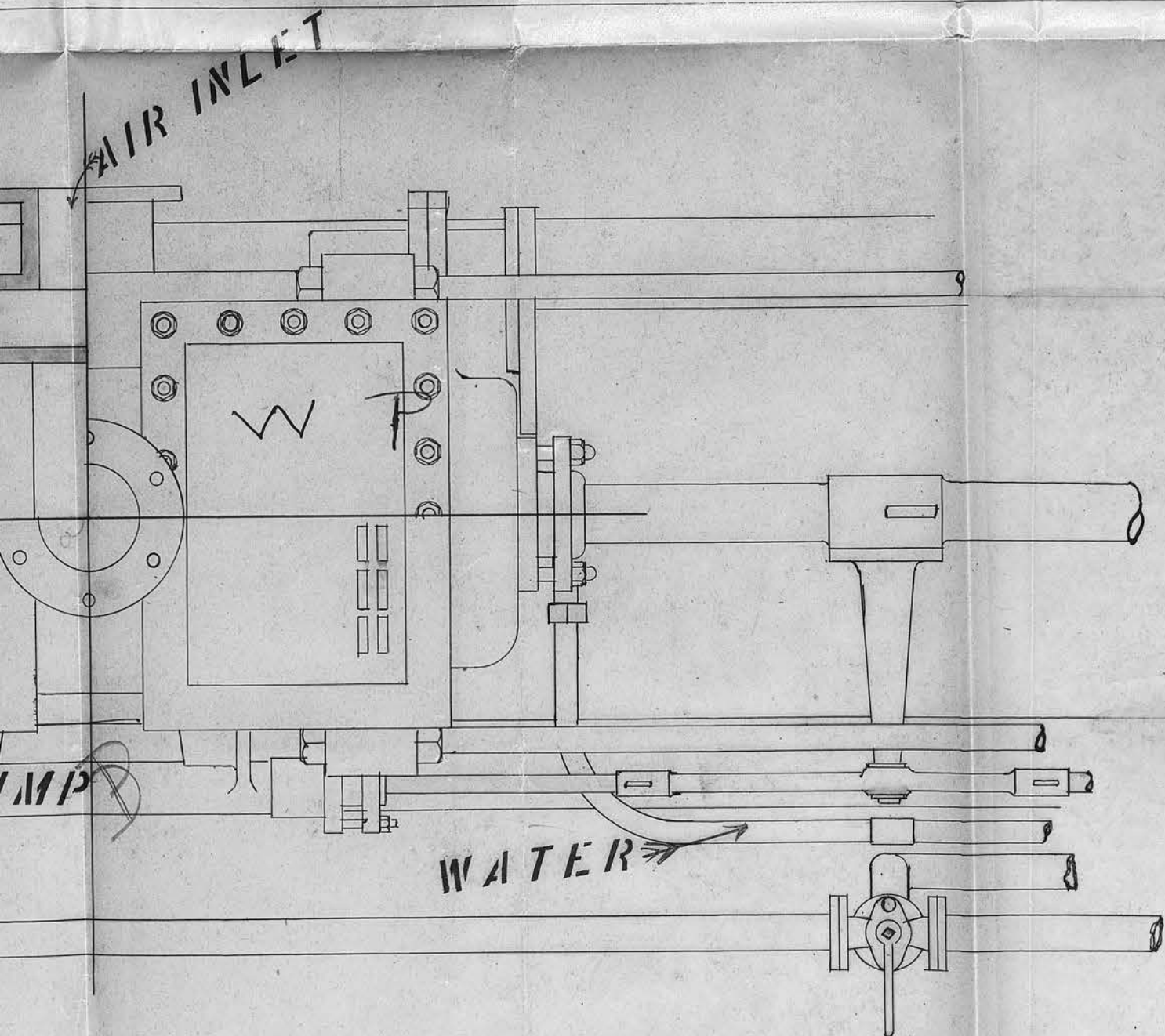
FORTH BRIDGE

COMPRESSING ENGINE





SCALE $1\frac{1}{2}$ IN



SCALE $1\frac{1}{2}$ IN = ONE FOOT

first in consequence of the burning of lamps &c within the Chamber, was subsequently greatly lessened by the use of Electric light; the bright illumination of which at a depth of sixty feet below the surface of the water was in no small measure wonderful.

Means used for Compressing air

Means of
Compressing
Air

The essential elements for air compression are An Engine, a Receiver, and an Air Chamber.

The lower portion of a caisson formed the Air Chamber.

The receiver was sometimes dispensed with; the air being forced direct from the Condensing Engine to the Air-Chamber.

The Air pump is driven by an ordinary steam Engine.

The piston rod, (accompanying plan R), is common to both the cylinders of the pump P,

Air Pump

and of the Steam-engine (E).

The principle of action is as follows:-
At either end of the air-cylinder (A) is an inlet valve (I), and a discharge valve (D).

There are thus two inlet and two discharge valves.

Both discharge valves have a common Outlet leading either to the Receiver or direct to the Caisson.

On the piston being drawn forwards, from either end of the Cylinder the inlet valve opens, owing to a partial vacuum being formed. This continues to the end of the stroke.

So soon as the motion of the piston is reversed, the inlet valve closes, and the discharge valve opens.

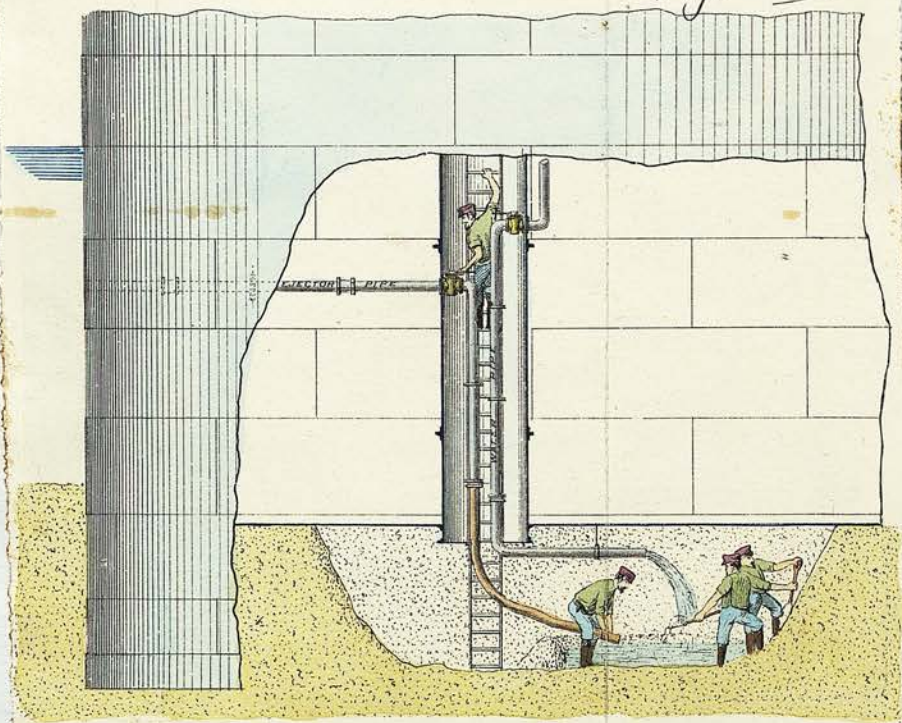
The air thus finds its way through the discharge valve on towards the Outlet and Receiver.

Action of

Air Pump

FORTH BRIDGE.
MODE OF EJECTING MUD AND SILT.

Figure III



The same description applies ~~so~~ to the action at the other end of the cylinder.

Water Pumps
of
Air Compressor

The engine is also provided with two water pumps (W.P.), the object of which is to provide for a spray of water being discharged into each end of the cylinder, to keep the air cool during compression.

In some instances Hyoraulic power is used in working the Air Compressor, the advantage of it being, that the air is not heated or otherwise rendered impure. The air at the end of the Forth Bridge jetty - a distance of 2000 feet from the shore, might be regarded as practically pure.

For therapeutic purposes however, the air may be filtered, by having a box containing Cotton-wool through which the inlet-pipe passes, immediately before

entering the air-chamber.

This box in hot weather may be filled with ice and thereby the temperature be suitably reduced.

The compressed air was led in iron pipes, from the compressor to a point near the caisson, and afterwards by means of a flexible tube, to a check-valve in the air shaft, whence it passed into the working chamber.

Similarly water was led from a raised tank, to a pipe on the working platform, from which by smaller pipes it was distributed inside the chamber for the purpose of diluting the soft mud (Fig III), which formed the first fifteen feet or so of the material requiring to be removed.

Entrance to
Air Chamber
through an
Air lock

Mode of Entrance into Air-Chamber
When a person desires to descend to
the air Chamber, he enters within
the outer door of the air-lock
(Fig IV sectional view D O), securely
fastening it behind him.

Thereupon he opens the stopcock T,
admitting the compressed air, and
when the degree of compression of
the air shaft has been reached in
the lock. the inner door D I, of
the lock may easily be opened, and
descent to the chamber made.

Conversely when wishing to leave the
working Chamber a person enters
the air lock from the shaft fasten-
ing firmly in this instance the
inner door of the lock.

He then turns the outlet stop-cock T,
permitting of the escape of the
compressed air in the lock,
Once this has been effected the
outer door of the air lock can
readily be opened, and exit made.

Exit from
Air lock

Physiological Effects of Compressed Air

Physiological
Effects of
Compressed Air

On entering an air-lock for the first time there is naturally felt a certain amount of excitement, induced by the feeling of, in the event of mishap, of helpless isolation.

Pain in
Middle Ear

On turning on the stopcock which admits compressed air, a very unpleasant sense of discomfort and pain referred to the neighbourhood of the middle ear is experienced.

Causes of
pain

This sensation is due to the difficulty of equalizing the pressure on either side of the membrana tympani, owing to the unequal calibres on the one hand, of the passage from the outer ear to the drum membrane, and of the Eustachian tube on the other. This inequality is frequently rendered greater, by the existence of chronic catarrh with consequent partial narrowing of the Eustachian tube,

or again, by the entrance being at-
tempted whilst a person is suffer-
ing from coryza with sore throat,
in which case the continuous
tumefaction of the tube, makes
its calibre less, and renders the
distension of its walls ~~by~~ more
difficult and more painful.

The result of this is, that the
membrana is pressed inwards,
to an extent that is associated
with pain more or less severe.

To obviate the sense of suffering,
one has an instinctive desire
to swallow, which act opens the
Eustachian tube, and probably
also allows a more abundant
column of air to enter than is
possible by nasal inspiration
alone.

It frequently happens, however,
that just when the effect of
swallowing would be most useful,
there is an absolute want of
saliva. secretion, and consequently

Method for
relief of
the pain

its repetition (i.e. of swallowing), is difficult or impossible.

In such cases one finds that Eating a biscuit & thereby stimulating Saliva secretion, and necessitating swallowing, is serviceable.

Further methods
for relief of pain

Another favourite method of lessening the pain is to practise frequently Valsalva's method of middle ear inflation.

This of course acts in a way similar to swallowing.

Placing cotton wool in the outer ear passage and thus rendering the column of entering air smaller and more broken, may also be advantageously used.

In my instance, I was forcibly struck by the occurrence of acute suffering in the right nostril, none of my friends experienced this, but on reflection I recalled to my mind the fact that years ago, in Vienna, I had

Pain from
striction in
nostril

found it extremely difficult to pass the smallest size of an Eustachian catheter along my right nostril, whilst by ~~passing~~ the left an instrument of medium size could readily be passed.

The cause of the pain was, in all probability therefore, due to the presence of a stricture in my right nostril, and to the dilatation of it by the passage of a bougie, in the form of an arial column, which increased in size with the increase of air pressure.

By the time that the requisite amount of pressure had been reached, the ear pain had usually vanished. In exceptional cases, however, the suffering was so excessive that persons could not or dared not proceed further.

Bleeding
from Ear
passage

Bleeding from the ear passage has been reported in the cases of persons in whom granulations near, or perforations of the Membrana existed, - ^{from the hypotids,} or when the individual had entered suffering from Coryza.

The following note illustrates such cases,

Feb. 10, 1885, Besonnores, a Frenchman, has worked 5½ years in Caissons, with a pressure reaching as high as 39 lbs above the normal pressure, & has never had joint pains; - to which reference is made hereafter.

Case of
Epistaxis
from Caisson
pressure

on the 8th Feb he worked under a pressure of 21 lbs, - had had a cold previously, - immediately on entering the Caisson he felt severe pain in both nostrils, a little in both ears, and over the frontal sinuses. He remained in the Caisson however during the hatch, but on leaving, he again suffered severely

in both nostrils, which was followed and relieved by the occurrence of violent Epistaxis, - continuing for some hours.

Discomfort
increased by
turning on
stop-cock fuel

The discomfort felt on entering the air lock was greatly increased by turning on the stop-cock, fuel, which workmen and others who had made the descent frequently were fond of doing. A diminished rapidity of the entering air column always lessened the suffering.

Character of
breathing in
compressed air

The character of the breathing is altered somewhat. It has always been observed that the inspirations and expirations were carried on more than usually completely, and that consequently the number of respirations per minute was lessened.

I was impressed with the fact that the breathing was in character

Character of
breathing
continued

much more than naturally
Abdomino-Thoracic,
the alternate distension and
retraction of the Abdominal
walls being very striking.
It is probable that one can
with more ease control the use
of the Abdominal muscles, than
he can raise the heavier bony
framework of the Thorax.
Observers have found that the
diaphragm descended lower,
that the lungs covered over more
of the heart surface anteriorly,
lessening therefore the area of
cardiac dulness, and that
posteriorly with the diaphrag-
matic, there was also hepatic
lowering, and consequently a
smaller area of dulness.
Owing to the more ultimate air
residues becoming expanded, the
vital capacity of the Chest is
very considerably increased.
And it seems to be probable

that in this, as in the greater descent of the diaphragm, - the excessive use of the Abdominal muscles plays an important part.

The lessening of the number of respirations per minute has been variously stated by different authors.

Number of
Respirations
per minute

Dr. Theodore Williams observes, that they (the respirations) have been known to fall from 16 or 20 to 4 or 5 or even 3 or 4 per minute.

Von Videnot remarks, that the frequency may be lessened by from 1 to 4 movements per minute.

I have never met with any case, either a visitor or a constant labourer in prisons, in whom the amount of reduction was such as has been stated by Williams, 12 to 14 respirations per minute being ^{the} average of many cases which I carefully observed.

Respiration is very deep and easy. It was difficult for me, owing to the constant noise of machinery, to define accurately the limits of the Cardiac Dullness, or to ascertain if, as is stated, the posterior hepatic Dullness is entirely obscured.

The diminished sense of resistance on percussion, however, which attempts to prove these facts elicited, gave indication to my mind, that certainly both ~~of these~~ organs have their usual surface areas, overlapped by the extra lung expansion.

Notwithstanding the diminished frequency of respiration, there is a much greater than ordinary absorption of Oxygen, and at the same time an increased proportion of carbonic acid formation, which was found by von Vivienot - who, with 3.7 atmospheres, 22 per cent more than at the normal pressure.

The compression of the lung during expiration, is also increased,

Oxygen Ab-
sorption and

Carbonic Acid
Formation in

Compressed Air

Lung Compression
in expiration

And a considerable flattening of the
Flattening of convex abdominal wall is pro-
Abdominal Wall - duced^{ed}, owing to the compression
 of gases existing in the intestinal
 canal.

Effect on
Circulation Williams, writing of the Effect of
 Compressed air on the circulation
 says, that the pulse is slower,
 smaller in volume, but of in-
 creased arterial tension.

Diminished
frequency
of pulse The amount of diminution in
 frequency varies, from 4 to 20
 beats per minute; and if the
 pulse have been somewhat exci-
 ted before entering the bath
 the diminution may be still
 greater.

Vivienot remarks, that the
 pulse rate diminishes from
 4 to 7 beats per minute, - the
 diminution being greater when
 there has been an abnormal
 increase.

I can only suppose in regard
 to these observations that

They have been made some time after the individuals have been in the air bath, for I have invariably found that the primary effect of compressed air is to accelerate the heart's action.

My method was to number the pulse before entering the air-lock, and again whilst in the lock, and, in the latter instance, there was always an increase more or less considerable, which was noticed in those who had entered a

caisson for the first time, and in whom excitement may be imagined to have had some effect; as well as in those who had made numerous descents, who had indeed been accustomed to caisson work for years.

It is the case, however, that after remaining in the Air-Chamber for a considerable period, the pulse becomes slower than normal. Thus my own pulse, which is usually about

Primary Effect
of Compressed Air
on Heart is Acceleration

Method of
Counting
Pulse
Before and After
Entrance into
Air Chamber

Effect of Com
pressed Air
After a Sojourn
in Air Chamber

72 per minute, was generally after an hour's sojourn in the Chamber, as low as 62.

But my point is - the primary acceleration -.

Dr Janinet's observations on the men at the construction of the St Louis Bridge, tend to confirm my opinion in this respect. He quotes a series of cases in which before entering the pulser were respectively,

81. 78. 78. 79. 79 + 80

At the end of six minutes in the air lock the pulser were,

100. 88. 98. 86. 95 + 90

At the end of two hours in the Air Chamber they were, 68. 70. 70. 69. 70 + 72

After climbing the stairs on their exit from the prison they were

106. 104. 92. 94. 102 + 99.

Janinet's ob-
servations on
pulsers under
various stages
of air compression

On the 27th January 1886, several friends descended No. 4. Caisson with me, when the following pulse records were taken.

Monte's ob-
servations on
pulses during
different stages
of Air Com-
pression

Before entering the Air lock;

80 90 88 76 - 82

In the air lock they were,

100. 104. 100. 102. 106

After having remained an hour & a half in the Caisson they were

74. 78. 76. 72. 72.

After climbing the stairs from the Air Chamber they were

104. 96. 88 96. 95

The quickened pulses in two of the cases before entering, was attributable to excitement, the descent being their first one.

The temperature of the outer atmosphere was 58 degrees, - of the Caisson i.e. the Air Chamber 61.5;

Temperatures
of outside air
& of Air Chamber

And of the Air-lock during decompression 50° degrees.

Temperature
of Air lock

The different degrees of temperature between the air chamber, & the air-lock, during decompression are very striking, and this difference, taken with other features attendant upon decompression is found to be a powerful factor in the production of certain pathologic states to be referred to hereafter.

Difference in
temperature between
Air lock and
Air Chamber

It was quite a common occurrence for the escape tube to become blocked with ice.

Blocking of
escape tube
with ice

The atmosphere at the same time becomes loaded with moisture, owing to ~~the air~~^{its} being unable to retain in suspension the same quantity held thus, during an increased pressure.

Cause of mist
in air lock
during decom-
pression

The inspiration of this cold mist frequently induces coughing, & to a less degree the Ear pain felt during compression, is now also experienced.

Cause of Cough
during decom-
pression

Ear pain &c

Amongst laison labourers slow pulses were invariable.

Even in men who had worked for 4 hours under a pressure of 20 lbs and upwards, the average rate was from 50 to 65, 44 being a number frequently enough met with.

The cause of the primary acceleration of heart's action is probably to be found in the greater amount of Oxygen absorption, with increased stimulation of the Cardio-motor centre.

The subsequent diminished frequency ^{is} being principally mechanical. The system having become habituated to the changed circumstances, the true effect of increased resistance to the cardiac systole is appreciable in the slower pulse wave.

The pulse is considerably smaller, and there is evidently increased

Slow pulses
Amongst
Laison Workers

Cause of
Primary Acceleration of Heart

Cause of
Diminished
Frequency

Character of
Pulse

arterial tension.

Sphygmo-
graphic tracings

The accompanying Sphygmographic tracings, taken with Dudgeon's instrument, show in degrees of greater or less clearness, the effects of compressed air on different parts of the pulse wave.

Nos 1, 2, & 3- are tracings taken before entering the air lock.



(1) Mr. Harrison 4/2/96 before going into air lock 34



(2) Mr. Harrison same time as (1)



(3) Mr. Harrison same condition as (1)

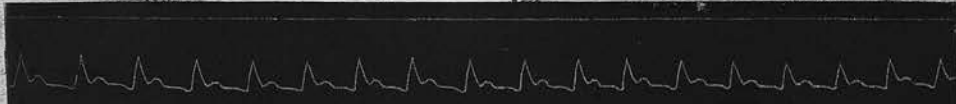
Tracings
before entering
air lock

Nos 4 & 5. Of the same individual in the caisson show the influence of a cardio-exciting character.



Mr. Harrison 3rd

Caisson in 16th



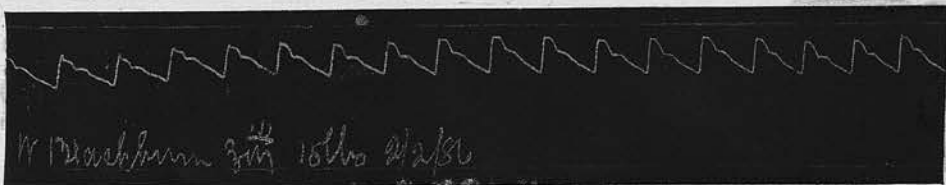
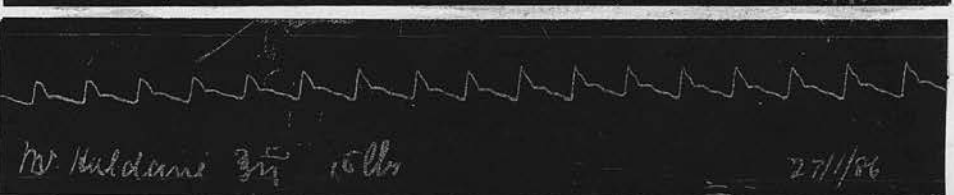
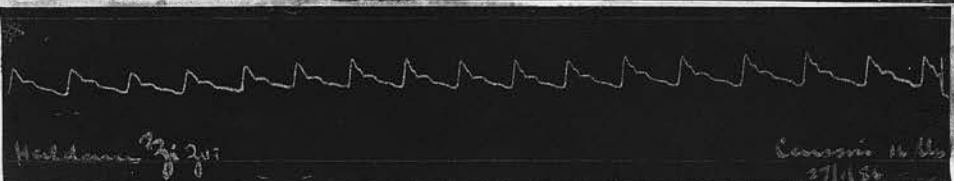
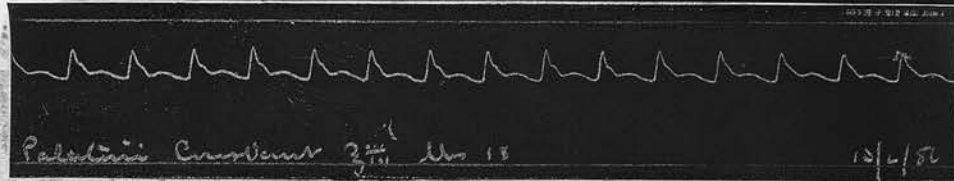
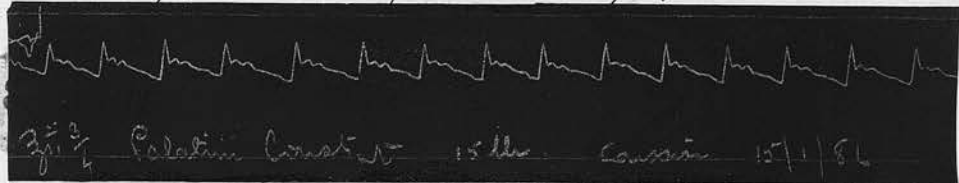
Mr. Harrison 15th

10/2/96

Tracings in
Caisson
showing ap-
plied pulse wave

Similar evidence of cardiac excitement, in hearts usually quiet + calm, is shown in the following tracings.

Additional
tracings to
show excite-
ment soon
after subroin-
in Chamber

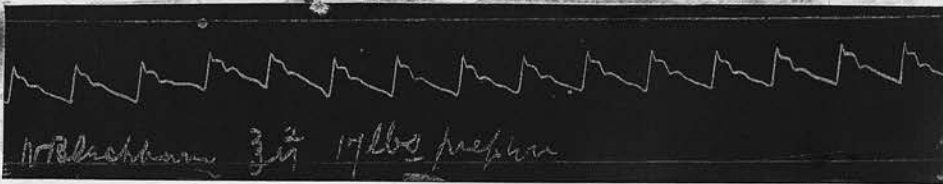
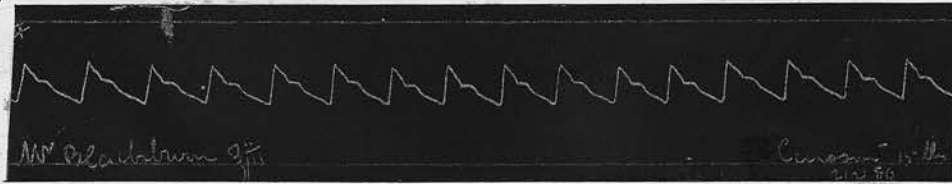


The next three tracings show the excited & quickened action of the air-lock, succeeded by the quieted & slower rate in the working chamber.

Pulse in Airlock
Heart excited



Pulse tracings
of same person
in Air Chamber
Heart quieted



The two following tracings of the same individual. Taken the one in my Con-
sulting room & the other in a Caisson Con-
trast marked.

Tracing in
upper Air



to contrast with
tracing of same
individual in
Caisson



(page 381)

The two following tracings, are intended to illustrate some of the points of difference between the heart's action under ordinary conditions of life, on the one hand, and during work under compressed air, on the other.

The difference will be noted to exist principally in that part of the pulse wave between from the commencement of the Ventricular systole, to the closure of the Aortic valves.

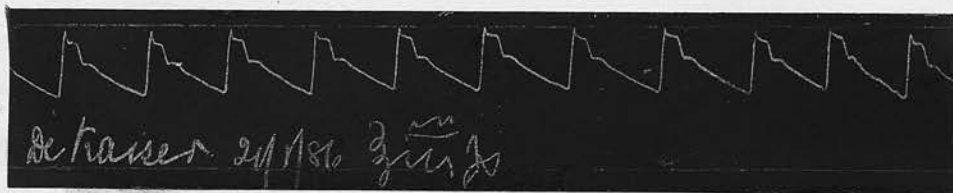
The line of descent though not quite so oblique resembles more the descent line at the usual pressure.

First, then, the up stroke is very considerably longer and more pointed, the apex of the tracing being very sharp.

Next, the distance between the apex and the pre-dicrotic notch is much longer, and the notch itself is very conspicuous, indicating a degree of arterial tension.

Points of
Difference
between tracing
under ordinary
and compressed
air

The eminence succeeding the pre-dichrotic notch is also more clearly defined, & the distance between this and the dichrotic notch itself is slightly longer than that shown in the other tracing.



A similar though less striking difference is shown in the following rather infrequent tracings.



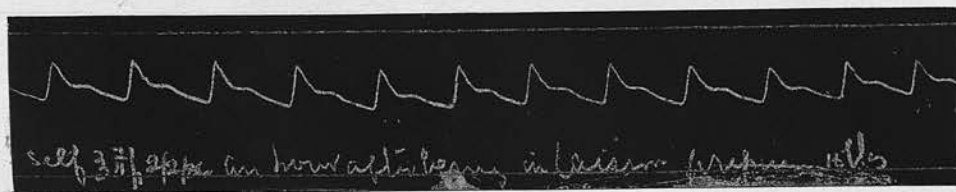
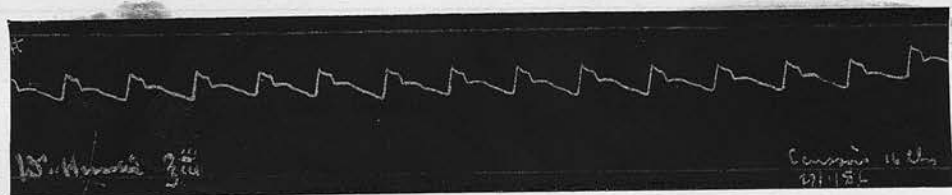
Other two tracings

showing some

differences

The next two tracings which one intended to show the difference between the pulse wave during, and after compression, suggest the idea that in some instances, the wave is lower in the air bath.

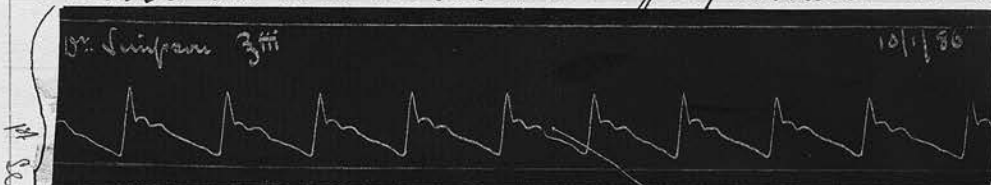
Tracings to
show difference
of wave during
and after com-
pression



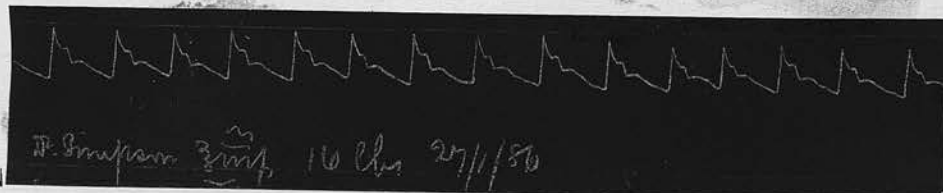
Theodore Williams states, that in the air-bath as a remedial agent the pulse is always lowered.

The two following series, ^(1/1/39-40) of tracings tend in the direction of agreement with this

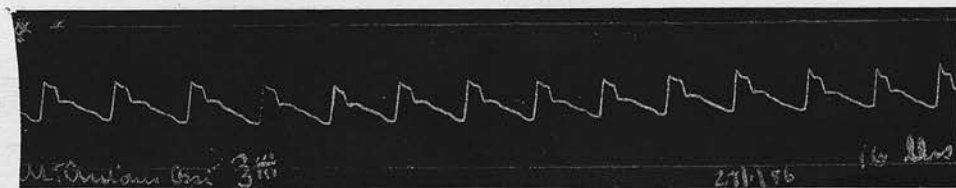
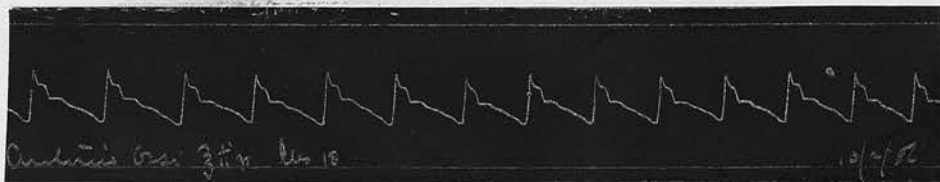
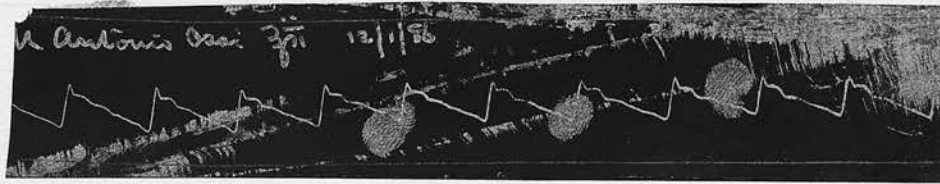
the series of
tracings in
which the
pulse wave is
lowered during
compression



- pulse in diff. air



- pulse in air



The two series above given, however, are tracings of individuals who only made occasional visits, and, in whom, the effect of physical effort, could not be calculated upon.

The majority of my tracings confirm Draper's remark, that the curve is above that obtained in normal air.

Across the series
showing same
condition

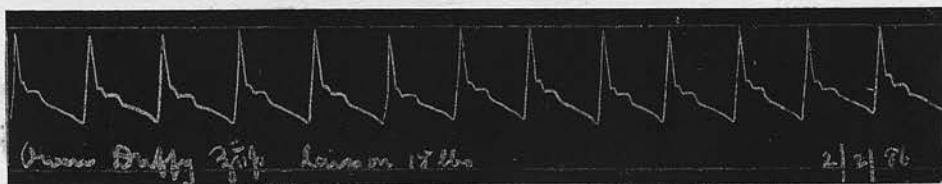
No. 1 & 2 - are
tracings in
upper air.

No. 3 & 4 are
tracings in
Caeson

difference
between pure
tracing of
an occasional
visit to, &
a worker in
a Caeson

The interest of the following tracings - in two sets of 4 each - lies in the fact that they are those of an Irishman, who did Caisson labour, though he had no previous experience of it. The Caisson tracings will be seen to differ markedly from those taken at ordinary pressure, the increased length of up-stroke & the pre-diastolic notch - being evident.

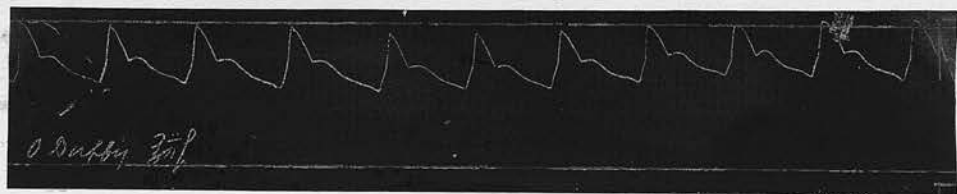
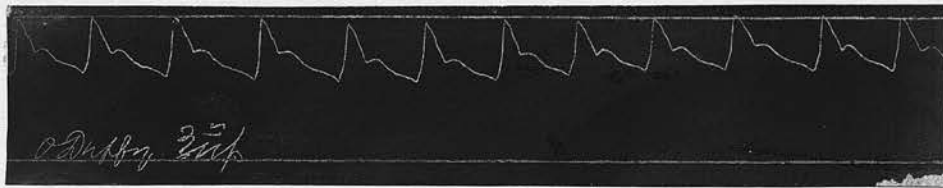
Tracings of
a person not
accustomed
to Caisson work
taken in the
caisson & in
the upper air



Tracings
taken whilst
the person
was at
work -
in the caisson



Tracings of the
same person
in the upper
air



I do not think it needful to multiply illustrations of tracings.

The points of difference, to which in the preceding pages I have directed attention, are equally with those included in this paper, shown in some seventy tracings (taken under compressed air), still in my possession.

Intropulsive
effect on
the Cutaneous
Circulatory
system

There is a marked influence of an intropulsive character upon the circulatory system. The vessels of the skin and immediately sub-jacent structures, are more or less emptied, and the blood is driven into closed cavities, such as the skull & joints, as well as into internal solid organs like the liver and spleen.

Evidence;

This consequence is noticed in the much finer calibre of the vessels of the membrana tympani and of the fundus oculi.

Joint notes
in a rabbit
Circulatory
system under
compression

Took opportunity of testing this point in the instance of a white rabbit which I took down one of the throats.

The markedly lessened pinkness of the Ears, & of the vessels of the conjunctiva and Iris. being very apparent, whilst by means of the Ophthalmoscope, I was enabled to note the pnce, thready look of the vessels of the fundus,

showing thus the intropulsive effect, in the case of an animal whose circulation was sensitive, of increased pressure.

Otherwise the rabbit, which was kept below for fully two hours, under a pressure of 20 lbs, was seemingly uninfluenced and did not sustain injury.

The same intropulsive effect of air compression, on the Circulation, was further noticed in the fact, that some people, myself amongst the number, suffered from frontal headache for several days after exposure to its influence.

The probable explanation ^{was,} being that during compression there is over distension of the vessels of the frontal sinus, and that these vessels do not recover their normal calibre or tone for some time afterwards, the congested state of the sinus wall inducing headache.

Frontal headache
lasting
(in some people)
for a time after
sojourn in
Air Chamber

Probable
cause of -

Was not able with frequent observation to notice that the vessels of the human fundus oculi were much lessened in size.

This may have been due, however, partly to the stooping posture necessitated by the nature of the work engaged in.

The increased oxidation in compressed air is supposed to produce an increase in the temperature of the body, and it is stated that this fact can be more correctly estimated when the temperature is taken by the mouth.

Noted frequently the temperature of laborers in the faissou, as well as of visitors there; but my results were by no means uniform.

In some instances pyrexia to the extent of nearly a degree existed, in others the arrow of health was not reached; and in many there

Temperature
in Compressed
Air

Varied Results
of Takings

was no variation from the normal standard. My takings, however, were all oscillary, still if there were invariably a difference in temperatures taken by the mouth or rectum, one would expect to find it also in axillary records.

McNamee writes, that the increased oxidation which occurs with animals inspiring condensed oxygen does not, as one would expect, produce an increase of temperature, but is attended on the contrary with marked lessening thereof.

It is possible therefore, that the increased oxidation consequent upon life and work in compressed air, is influenced by some unascertained cause, similar to that operating in the inspiration of condensed oxygen, and altering the effects which, a priori, one would expect to be produced.

Berth's Theory
as to cause
of diminished
temperature
in inspiration
of condensed
oxygen

Character of
Voice

The character of the voice also is changed. One's sense of hearing is to a small extent lessened, and in speaking the voice is pitched higher than usual.

Tone of voice

The tone of the voice is distinctly nasal.

Difficulty in
Whistling

One finds it impossible at first, and always difficult, to whistle, owing to the effort needed to make the dense air vibrate sufficiently. If however the attempt be made kneeling, and with the face turned downwards, the result will be more satisfactory. An obscuring of the special senses smell, taste and touch, has also been observed.

Albumen in
Urine

Professor Meigs, in a lecture on Puerperal disease, states that he found in a patient who came under his care suffering from pressure symptoms, a very small trace of Albumen ^{in the urine} which lasted for several days.

Not generally
observed

Other observers have not remarked this, though one would certainly expect that in cases in which the efforts of the system to recover from the intro-pulsive effects of the increased pressure were not speedily successful, that temporary renal congestion with Albumen should exist.

Refractive
amongst
foreign workmen
against collect
-in urine of
24 hours

I could not by any means, not even by money bribes, induce the foreign workmen to collect the whole amount of urine passed by them during 24 hours, so that I cannot speak definitely as to the relative amount passed during that time. I believe, however, that Jammet and others are correct in their statement, that there is a considerable increase in the daily secretion.

Increase in
amount of
urine
passed

I examined amongst others the following four specimens, specially with regard to the amount of Urea excretion.

Urine of
-amateurs

I De Boeck

Sp. gr 1025.5 Urea 1.7 grammes No Albumen

II De Bras

Sp. gr 1024. Urea 2.2 grammes No Albumen

III Stm Emmanuel

Sp. gr 1025. Urea 1.95 grammes No Albumen

IV Liron

Sp. gr 1022. Urea 2.15 grammes No Albumen

These were the Urines of healthy Parisian workers, & the noteworthy features, in addition to the absence of Albumen, will be seen in the large amount of Urea excretion.

Further experience may also justify the fair inference from these cases, that in health Albumen is not a necessary concomitant of

Cases of
urine examined
specimens with
specimens
urine secretion

increase in
amount of

Absence of
Albumen

Inference from

laisson work.

Improvement
in Appetite

Thin ref. men

By an occasional sojourn to a
laisson, one is conscious of
improvement in appetite, ~~at~~
~~yet~~ men accustomed to ~~laisson~~ work
are generally thin, indeed Dr. Smith
found that men with a tendency
^{to corpulence} were unfitted to stand the work.

Anemia
Thin ref.

In the case of the men employed at
the Inchgarvie laissons, where the
highest amount of pressure was
required, & where for a time the
hours of work were relatively longer,
Anemia and Thinness were very
noticeable features.

Causes of

The anemia was in all likelihood
due to the want of opportunity
of exposure to sun-light, as well
as to the influence on the
hemopoietic system of the severe
pressure.

Pathological Effects of Compressed Air

General Features of the Caisson work.

The sinking of the caissons was carried out by a M. Loisseau, who employed for the purpose a staff of foreign workmen, French, Belgians, Italians, and Prussians, all men who had been accustomed to similar work, & who were selected for the Fort Brive because of their former proved suitability.

They were mostly young & healthy working men.

Their hours of labour were from 4 to 6 hours, with a like period of rest, - except when the Inchegarrie Caissons were being sunk. There 4 hours of work were succeeded by 8 hours of rest, the former method having been found to seriously affect the men's health.

The amount of pressure employed, varied from 15 to 34 pounds above the

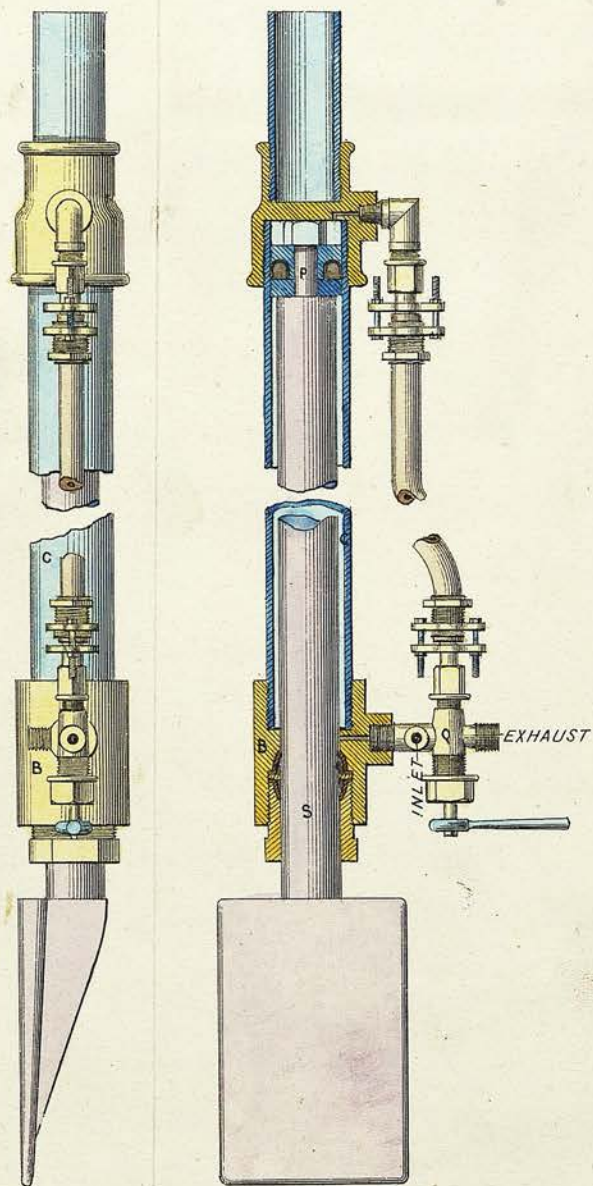
Men who
sunk the
Caissons
rationality
fitness

Class of men

Hours of work

Amount of pressure

FORTH BRIDGE.
HYDRAULIC SPADE.



normal pressure, being greatest in the process of removing^a the soft mud¹⁴ & the rock. The most dangerous time for caisson work-ers was 1st, whilst the soft silt was being removed, owing to the excessive dampness as well as perhaps to the presence of decaying animal matter, & 2nd, when the process of concreting was being carried on after a caisson had reached its proper depth, this being due partly to the want of a renewed supply of fresh air, & partly to the development of an excessive amount of carbonic acid gas. The cases of illness met with during these two epochs were, in number, out of all proportion to those occurring during the excavation of the boulev clay or of the rock.

For a time the excavation of the clay referred to taxed very much the energies of the men.

The labour implied in cutting through 20 feet of this hard material, of which it was impossible to dislodge with one stroke of a pick-axe a piece larger than ones

Most dangerous
time for work

Cause of

Decrease in number
of cases of illness
during

Difficulties in
excavating the
hard boulev
clay

Possible
Danger of
this kind work

hand, must have been very seriously
on their ^{the "hygiene"} health, & it may be, - would have
cost many lives; if M. Arne had
not devised a most ingenious machine
termed a hydraulic spade, of which
a drawing is annexed;

Hydraulic Spade

Save of

By means of this machine the clay
was easily dealt with, & labour reduced
to a minimum.

Compressed air
in drilling rock

Similar ingenuity was shown
when, at Inchgarvie, compressed air
was utilized in drilling the rock for
the insertion of charges of dynamite,
with which to effect its comminution.

1st Case of
Illness

The first case of illness amongst the
Caïson works was not Caïson disease,
but Enteric fever.

Typhoid fever

Cause of

The patient was a young Frenchman,
who a few days after the commence-
ment of sinking the first Caïson com-
plained of symptoms of Typhoid,
originating, supposed from the decom-
position of a vast number of fishes which
had become infected when the Caïson

rested fixedly on the mud.

Symptoms of Caisson disease

Caisson symptoms

history

Amongst the earliest of those affected with Caisson symptoms were several Belgians, who had completed the work of one watch under a pressure of 24 pounds, & who had thereafter proceeded to walk, on a cold, frosty day, to the huts where they lived. No sooner had they arrived there than several were taken violently ill.

As typical of these cases, I select that of Emmanuel Francois, a tall well built & healthy looking young man, who had been accustomed to caisson work.

He complained of most violent pain in the neighbourhood of the knee joint.

The pain began in the joint, and then extended for a short distance above & below it; quickly darting

History of

Typical case

Knee pain

Character of
Knee joint-
pain

again to its place of origin within the joint itself, having the feeling, as he described it, as if the leg and thigh were stretched as far as possible from each other, and were then allowed quickly to approximate again.

Pain in
other joints
less severe

He complained also of pain, of ~~pain~~ similar in character though less severe - in his shoulder and Elbow joints, by all of which he was rendered perfectly powerless.

Retention of
urine

In addition, Francois suffered for two days from retention of urine, a symptom which I noted in one other of the cases which came subsequently under observation.

Mitral murmur

I found on examination that Francois had a very marked mitral regurgitant murmur, on account of which I advised that he should not resume his work. Being a valuable workman, however, this advice was disregarded, with the penalty that, before

the sinking of all the caissons was concluded, Francois had a very severe attack of Pleuro Pneumonia. In the course of a week Francois & his fellow sufferers were able to resume work, and being now obliged to wear flannel, - a precaution which, considering their experience of the loss of heat during decompression & the fatigue of walking a considerable distance from the caissons to their dwellings, it seems strange they should have neglected, they withstood the effects of the work much better than before.

The joint pain is of all the symptoms the most constant, and almost invariably it attacks the knee, alone, or with other joints, rendering its poor victims, from its severity, absolutely helpless. One of three men whom I was called to see suffering from this condition, described the pain as being what he could imagine

Duration of
illness

Advised to
wear flannel

Loss of

Joint pains

Effect of

Knee painContinued

who produces, if a knife were thrust into the joint and turned back-wards & forwards until its contents had been removed.

It is difficult in deed, to conceive of pain in limited areas, being so violent as to produce the prostration following these Articular Storms.

Number of
Cases affected
both knee
pains

Five sixths of the cases affected, were with joint pains - alone, or in combination with other symptoms.

In some instances the pains were milder and of a character not unlike that of Rheumatism.

The following note may be regarded as typical of such cases.

First typeof Casesjoint pains

Aug 30. 1885. Angelini Dosi, a young Italian - engaged as a laicere superintendent, has mitral regurgitant murmur, otherwise healthy looking. Complaints of pains in the knee joints, beginning below the patella, shooting

upwards to the middle of the joint,
 & then extending some distance
 above the joint, attacking also
 the hip, and frequently the
 small of the back.

These pains have existed for some
 days, becoming aggravated towards
 evening; He has no Rhumatism.

Temp - $99^{\circ}.4$ Pulse 88.

He was ordered rest, warm flannel
 clothing, - and to take, morning
 & evening, a powder of Salicin with
 Dover's powder.

The day following there was little
 improvement, but on the third
 day the temperature & pulse were
 normal, and he gradually improved.

This might have been the note of
 an ordinary case of strabacuta
 Rheumatism. - But the man was
 a laison worker, his pains, though
 less severe, were similar in charac-
 ter to those of Francis & the other Belgians,
 occurring always after having
 been at work in a laison, and dis-

Similarity

to case of

strabacuta

Rheumatism

Differences

appearing under treatment when such work was temporarily discontinued. This case together with that of Francois suggested to my mind the possibility that persons with a heart lesion, would suffer more severely from laison symptoms. Subsequent observation, however, did not confirm this surmise.

At St. Louis, the laison workers were all subjected to repeated medical examinations as to their fitness for the work. Here, however, owing to the contract for the laison sink-
ing being in the hands of foreigners, with previous ~~similar~~ experience of similar work, no such pre-
caution was adopted. Otherwise naturally men physically unfitted such as the two cases noted, would have been rejected.

Another prominent symptom met with, was Epigastric pain accom-
panied by vomiting.

Medical Exam-
ination of
Laison workers
at St. Louis

Examination
not enforced
here -

Reason

Epigastric
pain &
vomiting

When such
a symptom
occurs

Frequently soon after leaving the
Caisson where he had felt well,
enough a man would suddenly
be seized with severe Epigastric
pain and vomiting, which might
be associated or not with the ar-
ticular pains referred to, or with
other symptoms.

The following note illustrates
this set of symptoms.

Sept 23, 1884

Illustrative

Case -

Was called to see a young Belgian
named Rayen, who complained
of Sicknepe, vomiting, pain in
the Epigastrium, & giddiness.
He had been at work in one of the
Inchgarvie Caissons till 2.p.m, when
his watch ceased. His room was
quite near the Caisson on the Island.
And, after having eaten a meal
heartily, he had changed his gar-
ments with the intention of coming
across to South Queensferry, when
he suddenly became unsteady,
and fell. His pulse, when I saw him,

was normal, and there was no elevation of temperature.

Symptoms

Continued

There were frequent attacks of painful retching, the continued completely unable to steady his movements, or to walk.

He had no joint pains, though a week before he had suffered from what he termed *la pression*, meaning thereby the articular pains described, along with slight retention of urine, which however the application of warmth had sufficed to relieve.

He had rested for two days, after which though feeling somewhat ill, he resumed work. He had had previous *laiss en experience*.

Treatment

He was ordered to lie perfectly still, to take milk & see, Bismuth and dilute Hydrocyanic acid being also prescribed. Next day his condition has improved, the pain in the Epigastrium was less severe, the sickness had diminished, & he could walk a little though mustily.

Progress

In the course of a week the symptoms ^{disappeared,} he returned to his home in Belgium, prudently fearing to resume caisson work.

Reference has been made in an earlier part of this paper to the occurrence of nasal haemorrhage following a visit to the caissons. Very different was the haemorrhage in the case of the young Italian, to whom the following note applies.

Haemoptysis

A. B. Has been accustomed to caisson work, and has already been some time at the Forth Bridge.

After leaving work one day he lay down to rest on deck of the ship *Hongoumont*, moored alongside the jetty about 300 yards from the caisson. Very soon he was seized with profuse haemoptysis, which I found proceeding from a portion of his right lung, immediately below the clavicle.

When it
arose from

The haemorrhage was, after a time checked, but the pulmonary irritation

Pneumonia
following the
Haemorrhage

set up through its presence, was the cause of an acute Lobar Pneumonia, from which the man nearly died.

Previous history

On enquiring I found that the patient had suffered some years ago from Haemoptysis, which then also, arose from the same part of the same lung. He had recovered however so sufficiently as to be able to resume his work which, no doubt, improved his health.

What this
case illustrates

This case may be taken as illustrative of the changes in the circulatory system produced by Compression and decompression. The intropulsive effect of Compression had probably ^{emptied} a condensed portion of lung substance of its blood supply, the same vessels, however, becoming overdistended during, and after the stage of decompression.

a second slight contraction of cutaneous Capillaries, owing to his exposure on the deck of the ship, produced a re-distension of the vessels of the subjacent lung with rupture

of one of the vessels, at a point where from malnutrition its coats had already been degenerated.

In this case there were no articular pains save those implied in the general malaise associated with a temperature of 105° , which attended the Pneumonia.

Treatment

I found the Friction of Hamamelidis most serviceable in restraining the hæmorrhage. The Pneumonia I treated on general principles, and as already indicated, with success.

Next Symptom

Giddiness headache

The next important symptom was Giddiness frequently accompanied by headache.

The subjoined note illustrates cases in which this has the prominent feature.

Fritz Ingovitz - a naturalised German, a tall thin man of about 48 years of age, - had been employed for some months as a labourer but had ^{had} no previous Saison experience.

Thinking to earn larger pay, he

Illustration

Case I

General features
of case

volunteered and was permitted to descend to the working chamber of No. 1. Laisson, where he remained employed during one watch, under a pressure of 20 lbs above the normal atmosphere. He felt well enough at work ^{continued so} and until he reached his lodging in Queensferry, about a mile distant from the Laisson, when he was suddenly seized with giddiness, and severe pain in the head. He reeled and staggered worse than a drunken man. He could not stand or walk a step without assistance, his invariable tendency being to stagger to the left.

Symptoms

He was assisted to bed, but even then everything seemed to wheel round, and the most uncomfortable sensation of poisonous giddiness continued. With the exception of the headache and the complete loss of the power of Equilibration, he suffered from no joint or other disturbance.

Treatment

He was ordered perfect quiet, and large doses of the Bromides of

Potass and Ammonium were given several times a day.

Certain amt
of improvement

Under this influence he, to a certain extent improved, and in the course of a few weeks was able, by the aid of a staff to come to my consulting room - a distance of 500 yards or so.

Progress in -

I used to put him at one end of the room and, placing ^{myself} vis-a-vis at the opposite end, ask him to walk straight towards me.

Tendency to
him to left

His attempts to accomplish this task were interesting, for he always most unwillingly found himself separated from me by the breadth of the apartment, his tendency continuing to incline his movements to the left.

There was no alteration in the structure of the membrana & beyond some venous fulness, no altered appearance of the fundus oculi.

Going to Alva

The patient went to his home at Alva in December 1884, & remained

Return to

Quincy

Condition then

Revised treat-
ment

Effect of

Therapy of

treatment

there till the middle of the March following, suffering from vertigo and headache, for which he was blistered and otherwise ineffectually treated. On his return, I found, on testing his progressive power as already described, that he reached a point parallel to me - about 3 feet to one side.

I prescribed again Bromide of Potass and combined with it Fluid Extract of Ergot in 20 minims doses, to be taken thrice daily.

The effect of this treatment was extraordinary. His headache daily improved, he could walk much more steadily; and in three weeks he had recovered so completely as to be able to resume his former work ^{as} of a lecturer.

I ordered these drugs on the assumption that there existed in this man, a congested condition of the vessels at the base of the brain, and of the upper part of the spinal cord,

which produced the distressing symptoms recorded.

I hoped the Ergot would contract the vessels of the Congested parts, and by partially emptying them relieve the vascular pressure, - the pain produced by which, indeed, it was believed, be allayed by the Bromide in large doses.

I was not ~~until~~ 18 months afterwards aware of the fact that Dr. A. H. Smith of New York had, on similar grounds, ^{also} recommended & successfully used Ergot in large doses & frequently repeated.

Several other cases of giddiness occurred, in all of which, with one exception, the tendency was to turn to the left. I am not informed of any reason why this special tendency should have existed, and its frequent occurrence may have been merely a coincidence.

None of my cases - one sixth or thereby of the men employed -

Rationale of
treatment
continued

Dr. Smith's
similar treat-
ment

Cause of
turning left

Number of
Cases affected

No fatal Case

proved fatal, and none of the illnesses are likely to lead to permanent disability.

AffectionsRemainingSubsequentto thisSymptoms

One man who suffered severely from joint pains, still complains of what seems to be a rheumatic affection of the muscles of his left Thigh, which is half an inch less in girth than its fellow, & is, moreover, remarkably sensitive to barometric changes.

Another person, who had Vertigo, still complains of deafness in one ear - that to which his tendency was to turn.

Number ofdeaths atSt Louis

At the Bridge of St Louis, - 13 deaths occurred, and the more grave symptoms of Caisson Disease such as Paralysis, & Coma, were frequently witnessed.

Same symptoms

Some of the cases of Paralysis lasted for a year, ending by death, others for a shorter period, & resulting in recovery more or less complete.

p.m. Examination

Changes found

Post-mortem examinations were made in the fatal cases, with the invariable finding of intense congestion of the brain & spinal cord, & their membranes, as well as the existence of some subarachnoid effusion.

There were also found haemorrhages into the kidneys, and injected areas, or even patches of Ecchymosis, in the Stomach, Intestines, & Bladder.

Leaving the

Air Chamber

at St Louis

After leaving the air chamber (during the earlier part of the work), the men had to climb ^{up more than} ~~over~~ 100 steps of a perpendicular ladder in order to get to the surface. This was terribly exhausting, & following the wearying effects already undergone of severe labour, was no doubt responsible for many of the deaths. During the latter progress of the work an Elevator was used, & with marked benefit.

At Fort Bridge

At the Fort Bridge the men climbed the stairs, but under the influence of compressed air, the air lock being at the top of the shaft, not immediately above the working chamber as at St Louis.

Theories as to the cause of Caisson Symptoms

Theories as to
Cause of Caisson
symptoms

Francois &
Bert's theory

Various opinions have been held as to the manner in which Caisson symptoms are produced.

Francois and Paul Bert held, that during compression of considerable degrees, the blood absorbs an amount of air or nitrogen, which is set free as bubbles when decompression takes place, interrupting the circulation.

And Bert claims to have discovered such bubbles post mortem, in the vessels of the brain and spinal cord. He is of opinion that the bubbles do not form if the pressure does not exceed 5 atmospheres and when 3 minutes are allowed for decompression.

This explanation cannot be held as always applicable, for, at the Forth Bridge as elsewhere, when the pressure did not nearly reach 5 atmospheres, & when more than 3 minutes were allowed for the stage of decompression Caisson symptoms have occurred.

Dr. Smith's theory

Dr. A. H. Smith insists that Bert's theory does not explain why some people escape laison symptoms altogether whilst others suffer so severely.

He (Dr. Smith) thinks that the cause is to be found in the changed conditions of the Circulation.

The compression causes all the cutaneous vessels to be emptied, and all the vessels of solid organs and of bony cavities which offer resistance to the compression to be filled to over-distension, the vessels becoming merely passive tubes. When the pressure is removed the emptied vessels are rapidly filled overdistended and paralyzed.

The vessels of the brain & spinal cord being most distended are less able to relieve themselves, the vaso-motor system being in areas paralyzed, owing to the suspension of function in trophic cells in the cortex or in the anterior horns of the cord.

Professor Bauer thinks that with the increased oxygenation and

Professor Bauer's
theory

Gannet's theory
Continued

tissue waste of organic structures taking place under compression, the blood necessarily carries with it more carbonic acid and other effete material. No harm follows this during compression, but when decompression occurs the increased oxygenation ceases, and the accumulation of waste material acts as a poison to the system.

Dr. Gannet's theory

Dr. Gannet, who had noted the increased amount of urine passed & the excessive amount of urea excreted, as also that the men at St. Louis perished at a lower temperature, is of opinion, that the cause of caisson symptoms exists in the increased and rapid tissue waste during compression. At four atmospheres he found that respiration was more rapid, that each man inspired four times as much oxygen as at ordinary pressure, and that consequently bodily waste went on four times as fast.

Professor Woodward's
theory

Professor Woodward, who wrote the history of the St Louis bridge, thinks that the symptoms are due to paralysis of vital energies owing to the great loss of heat, due I To the expansion of the air in the air-lock whilst coming out;
 II To the expansion of free gases and vapours within the body when relieved of the increased pressure;
 III To the liberation of the gases held in solution by the liquids of the body during compression;
 IV To the severe physical effort of climbing the stairs from the working chamber.

He noticed the fact that all the men felt cold on coming out of the compressed air, - the exhalation and increased vital energy of the air chamber being replaced, on leaving it, by a very low ebb of vitality, and by an all-pervading sense of frigid helplessness.

I think with Professor Meigs, that the real explanation is not contained in any one of these theories alone but that it is to be found in a combination of parts of all of them; different theories being accountable for different sets of symptoms.

Summary of
my opinion.
as to the cause
of various symptoms

- All the ^{alarming} symptoms are produced by decompression, nothing in the least degree detrimental to health occurring whilst one remains in the working chamber, even under a pressure of four atmospheres.

There is therefore in this stage ^(compression) a degree of increased vital activity proportionate to the degree of increase of pressure.

There is further, for mechanical reasons, an intro-pulsive effect on the cutaneous circulation, with an absorption of gases by the liquids of the body.

Were decompression to be effected sufficiently slowly, & with proper precautions, probably little would

It may be
symptoms might
be avoided

be heard of laceration symptoms. But by riveting methods it takes place with considerable rapidity.

There is a great giving out of heat, producing an extremely devitalizing effect on the workers.

Mr. Perry continued

There is a loss in the balance between oxygenation and tissue waste which ~~but~~ held during the increased vitality of compression. And there is a sudden liberation of ^{the} gases which had been absorbed, and which ^{now} tend to interrupt the circulation causing severe pain in the neighbourhood of the vascular fringes of joint surfaces.

But to me it seems that there is also a nerve element in the production of this severe pain.

Sir Joseph Fayrer has pointed out that in cases of *Sciatica*, he has obtained relief by incising the nerve sheath, releasing thereby a varying quantity of fluid which had accumulated within the

Suggestion as to
analogy between
Sciatica & the
Neuralgia of
Compression disease

Suggestion on

lines

sheath, and, by its painful pressure on the nerve substance proper, has given rise to the condition whose name indicates the locality of that specific neuralgia.

It is quite a possibility then, that there occurs in certain areas richly supplied with nerve filaments an absorption of Nitrogen during compression, by the Intra-perineurial fluid, and that the excessive pain referred to these areas is produced by the attempt at release of bubbles of the gas, when decompression has begun to take place.

Treatment

Treatment

Prevention

Preventive. The rules framed by the Managers of the St. Louis Bridge are so in accordance with ~~facts~~ conclusions drawn from ~~facts~~ which, in my experience I observed at this Bridge, that, in my opinion, the principles they embody should

receive the attention of all Directors of Caisson work.

Men should be healthy and well-fed. They should eat a meal an hour or so prior to their entering the air-chamber. The periods of labour should be diminished proportionately to the increase of pressure.

Perfect rest and warmth should be had for about an hour after coming out of the chamber. The use of an Elevator should be recommended always, and should be enforced, when the air lock is immediately above the working-chamber.

The increase and diminution of pressure during Compression and decompression respectively should be very gradual. The increase should not be more than six pounds per minute, and the diminution not more than four pounds per minute; and if when in the lock painfully unpleasant sensations continue after

Rules, which
Caisson Directors
should attend
to, & his interpreters.

middle ear inflation, swallowing &c, entrance to the working chamber should not be permitted.

Before leaving the air chamber (after severe physicial labour) each person should be served with hot tea, coffee or soup.

There should be separate entrance and exit locks, - the exit lock being provided with a heating apparatus to keep up a proper temperature and to furnish heat to the men.

On the Continent of Europe and in America, Caisson workers have been accustomed to wear, as a fancied safeguard, Galvanic bands, composed of alternate scales of Silver and Zinc.

These bands were worn round the ankles, wrists and other parts of the body likely to be affected with Caisson symptoms. It is not clear, however, that any real benefit was derived from their use.

Under con-
ditions

Use of
Galvanic bands
as a fancied
safeguard
against Caisson
symptoms

Active Treatment

Active treat-
ment.

In several instances here, men who, on coming from work felt Caisson symptoms threaten, immediately returned to the air Chamber when the pains vanished.

Return to
Compressed air
chambers

Doubtless, were this method of treatment always practicable, it would be found more likely than any other to yield good results. For on again entering the airlock, re-absorption of those gases whose liberation produced the distress, occurs, and care can be taken that, on subsequently emerging from the Chamber, decompression takes place gradually and with requisite slowness.

It is easy to understand, however, that in many cases it would be impossible to have patients taken back to the Air-Chamber, and the urgent symptoms therefore must be met & relieved otherwise.

Treated the severe joint pains by the application of electrical stimulus to the area affected, the theory of treatment being, that thereby the vital activity of the part where gas liberation had been interrupted, owing to the too rapid decompression, was temporarily increased.

Subsequent application of moist warmth to the joint, with the administration of a sedative, hypodermically or otherwise, generally afforded relief.

My experience would make me feel disposed to employ Ergot very hopefully in the treatment of the distressing symptom of Giddiness. Jammet & Smith speak very highly of the value of Alcoholic Stimulants with ginger in cases where Epigastric pain is a prominent symptom. Vomiting is best treated with Ice. And other symptoms must be met according to the indications of the special circumstances in which they exist.

Electricity to
paralyze joint

Moist warmth
also to joint

Morphine -

Ergot for
Giddiness

Alcohol for Epi
gastric pain

Ice & vomiting

Compressed Air as a means of Treatment

I do not propose to enter at any length into the therapeutic uses of compressed air. For, naturally the activity associated with the construction of a gigantic bridge was not favourable to the testing of its use for medical purposes, and the nature of my present professional duties, likewise precludes the possibility of any attempt - which I may hope at some future time to make - at systematic use of this remedial agent.

Establishments where it is employed, however, exist to the number of ~~about~~ fifty at various places on the Continent. But in England they are to be found only at Ben Rhydding, Ilkley, and Brompton.

And, with the exception of Dr. Theodore Williams, & more recently of Dr. Sanger, no English physician has recorded any experience of its efficacy or the reverse.

Scotland, unlike its usual position

Compressed Air
Therapeutically
Considered

Number of
Establishments
in Continent

in England

Experience of
English Physicians

as a Pioneer in Medical science, cannot so far as I know, boast of one single establishment.

The expense of construction of the establishments and the time needful to devote to their attention, have no doubt proved powerful barriers to their extensive use.

But one is justified in hoping that with more extended trial the methods of application will become much simplified.

In addition to the Air baths for which the Caisson principle is suited, Compressed air may be inspired also through masks fitting closely to the mouth.

Of these masks numerous forms have been used. The form recommended by Dr. Garngree, is that of Professor Schmitzler. It consists essentially of two Cylinders, one for condensing and the other for rarefying the air.

Both are connected by pipes with

Scotland having
no establish-
ment

Drawn here has to their
extensive use

Masks also
used for in-
spiration of
compressed air

the inhaling masks, and are provided with taps which regulate the supply of either for inhalation.

Millianus' ob-
jections to
these masks

Dr Millianus has found the use of these masks irksome, & he states that many complain of their inducing faintness and headache.

He believes moreover that, with them, it is impossible to keep up a proper supply of fresh air at the needed pressure, and that therefore there is risk of vitiated air being rebreathed. On these grounds he recommends & adopts the ^{best} air baths.

Gamgee's opinion

Dr Gamgee, in a more limited experience, has not found those drawbacks to which Dr Millianus refers. His difficulty has lain in the apparatus as used by Schnitzler, not being so correctly made as to yield results of desirable accuracy.

With more extended use however he hopes to remedy the defects, and to convince the profession of its therapeutic value.

Therapeutic
action of
Compressed air

Its mechanical
action

Therapeutically considered, Compressed air acts in a three-fold manner, (a) mechanically (b), physiologically, & (c) as a sedative. In virtue of its mechanical effects, its use is indicated in cases where an increased blood determination to certain internal organs, such for example as the ovaries, is likely to lead to an increased functional activity of these organs. It is contra-indicated, on the other hand, where, as in febrile states, congestion of internal organs already exists.

Thus, in a pulmonary congestion its use could only be productive of harm, unless to the extent that it actually led to the pulmonary blood supply being driven to more resisting organs.

Dr Williams' maxim - that its mechanical effect will be most useful in cases where congestion of the right side of the heart and of the liver exists.

On the pulmonary tissue itself, the mechanical effect of compressed air is most beneficial. In cases namely in which following an overfilling of

the vessels of the bronchial & alveolar walls, a catarrhal state of the tubes & alveoli has been induced, leading eventually to their being blocked & becoming functionally useless. In such cases the vessels are emptied by its use, the bronchi are rendered permeable, & the alveoli distended. The secretion is absorbed, the function of the lung restored, and the vital capacity of the chest markedly increased.

Owing to the mechanical effect on the intestinal gases, some surgeons have advocated its use in cases of strangulated hernia recommending that the vis should be resumed after the patient has been ~~for~~ a few minutes in the air bath.

Physiologically, Compressed air acts beneficially by introducing more Oxygen into the blood, affording thus means of more efficient saturation of the Oxyhaemoglobin, & inducing thereby more rapid tissue change, as for instance, in hastening the re-absorption of the catarrhal secretion already referred

Use in

Strangulated

hernia

Physiological

action

to, in treating of the action of compressed air mechanically; And by the larger proportion of Oxygen leading to increase in the number of red blood corpuscles, improving such conditions therefore, as Anæmia and Chlorosis.

Physicians have had difficulty in explaining the cause of the sedative effect of compressed air. It may be that the irritability of certain mucous membranes, & the muscular spasm common in some pathological states, are due to poverty of the centres regulating the nerve supply of the structures indicated, and that the better nutrition of these centres, consequent upon a more largely oxygenated blood, restores a more healthful peripheral nerve tone.

Dr Theodore Williams has recorded, in most full and interesting detail, a series of Eight cases of Pleurisy, Bronchitis, Emphysema, Asthma, Consolidation of lung following Pleuro Pneumonia, and Phthisis, in all of which the use of compressed air has

Use in

Anæmia &

Chlorosis

Its Sedative

Effect

Williams cases

resorted to with highly beneficial results.
Dr. Gamgee's experience is entirely
confirmatory.

My own experience extends only to
one case. Mr. G. aged 25. has been
subject to severe attacks of spas-
modic Asthma since Early Youth.
Has Emphysematous margins of
both lungs anteriorly.

Has twice in compressed air - once
in the Air lock only - on the other
occasion in the working chamber as well.
Remained for a considerable period
each time. - Pressure 18 & 22 lbs above
normal atmospheric pressure.
Had not an asthmatic seizure
thereafter for Eighteen months.

Gamgee's ex.

perience

Mountain case.