A Geotechnical Engineer's 7th Sense

The Fourth Laurits Bjerrum Memorial Lecture
Presented 19th March, 1979

By Elmo DiBiagio

The title of this lecture stems from the name of a combination pocket diary, reference book and almanac that is extensively used and well known in Norway. The name of this little book in Norwegian is 'Den 7de Sans', which means literally 'The 7th Sense'.

The reader will probably find that the style of this memorial lecture is a bit unconventional; since it does indeed differ from the kind of lecture one usually hears or is expected to give on such an occasion. In that I had complete freedom of choice regarding subject matter and method of presentation, I selected the following style for two reasons. Firstly, I wanted to show in my own way that a lecture of this kind does not necessarily have to constitute a major scientific contribution to our profession; for if this were the primary requirement then the number of persons who potentially could be called upon to present a memorial lecture would be unfairly restricted. Secondly, the winter of 1978–79 in Norway was abnormally long and severely cold. Those of us who endured it, I felt, needed something to make us laugh and forget for a few short hours the winter that had preoccupied us for so long.

The lecture is published exactly as it was presented. However, in order to clarify or explain some of the points that may not be fully understood by non-Norwegian readers a number of explanatory footnotes have been included.

Oslo, November 1979

Foreword

The most fragile part of a speech, and the part that is most difficult to organize, is the introduction. For it is here that the speaker must accomplish several important tasks within a very short period of time.

Even though I thought I knew what I wanted to say in this lecture, I kept getting sidetracked in the introduction. Ultimately I ended up writing three entirely different introductions to three potentially different lectures. After spending so much time and effort writing these introductions, I really didn't want to discard any of them. This, then created the hopelessly impossible situation wherein I had to somehow find a way of presenting the lecture topic in such a way that I could make use of three entirely different introductions.

Ladies and gentlemen, whether you feel up to it or not, and whether you want to or not, you are about to hear a lecture that, among other things, does have three introductions.

Thus, within the framework for this evening's presentation we will have:

- an introductory introduction,
- an intermediate introduction, and
- a concluding introduction.

Somewhere in between, if you are alert and play close attention, I am confident that you will even recognize bits and pieces of the main topic.

Introduction

For most of us, our day to day knowledge of what happens around us depends almost entirely on how closely we listen to our wives at the dinner table. Otherwise our ability to be conscious of things around us is determined by special powers of the body called senses. By the same token, our direct awareness of our surroundings is severely limited to what we can determine on the basis of our six inborn senses, namely:

- sight,
- sound,
- smell,
- touch,
- taste, and
- equilibrium or balance.

Our bodies are not equipped with any other receptory devices; thus, anything that can not be detected directly by these senses is literally invisible or unknown to us. This is of course a major deficiency of the human body, and in order to compensate for this deficiency man has laboured intensively through the ages to extend the operating range and capability of his senses, so to say. This has been done principally through the development of mathematics, experimental devices, and understandings that permit man to explore things that man alone can never see and will never directly know.

In addition to good old fashioned 'common sense', geotechnical engineers, like most other reasonable people, rely a great deal on their inborn senses in their daily work. Touch, smell and sight are used, for example, in classifying geotechnical materials and in some instances this type of information alone may be sufficient for an experienced engineer to arrive at an acceptable solution to a minor geotechnical problem. But it doesn't take much imagination to visualize how totally helpless we would be as consultants or research workers if the only information we have access to is that which can be derived from our senses alone. Imagine trying to design the foundation of a major structure on the basis of touch, smell, sight, and sound data, not to mention taste.

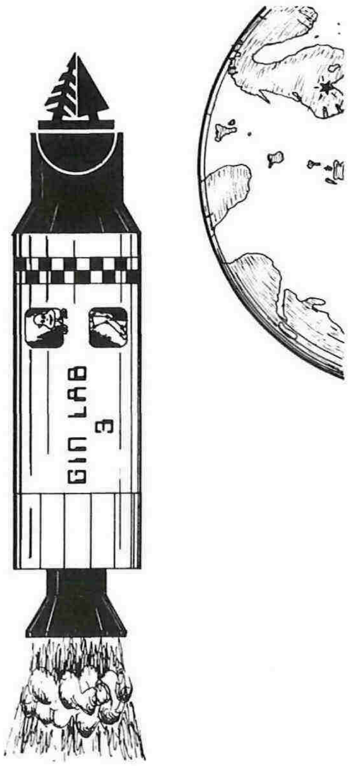
It is not surprising, therefore, that at an early stage in his own evolution, the geotechnical engineer recognized the need to overcome the physical limitation of his inborn senses. The remarkable thing is that as he used his ingenuity and native intelligence to devise ways and means of compensating for this deficiency he gradually developed and became master of a highly refined new sense – a pseudo 7th sense, so to say – that increased many fold the capability and usefulness of his other senses. The goal of our lecture this evening is to look into this peudo-7th sense, and we will do this in a somewhat unconventional manner.

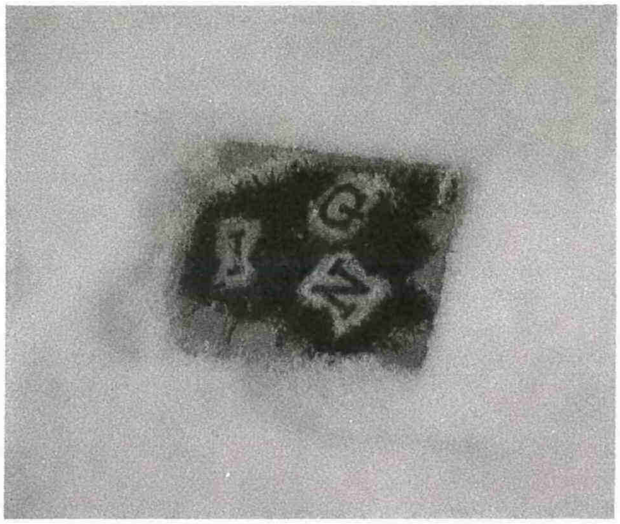
At one time or another we have all read fascinating accounts of the early history of the human race as reconstructed by archaeologists and anthropologists who have managed to unlock the secrets of the past through a meticulous study of the remains of material objects and fossils of human origin. When reading such accounts one can not help but wonder how future scholars will describe us and our civilization on the basis of the material we leave behind in our enormous junk yards and garbage dumps, or in our attics and desk drawers. This is exactly what we shall try to do together this evening. For the next hour or so let us pretend that we are archeologists and historians of a distant future generation who are trying to unravel the secrets of our own generation. On the basis of the paraphernalia that the geotechnical engineer left behind, let's try to ascertain what his mystical 7th sense was and how he made use of it.

In order to set the stage for our work this evening let us take a trip together into the distant future. Close your eyes and imagine that we are being transported far-far away in time and in distance.

SOMEWHERE IN OUTER SPACE ANNO 3000 AD

It is the year 3000 AD, and we are on an interplanetary space-ship speeding on its way to a rendezvous with the planet earth.




Remains of fabric and letters I, G and N found in glacial ice.

Our mission is to study archaeological remains of GEOMAN, a 20th century species of the human race, who is reputed to have had a unique 7th sense. Geoman is a subgroup of man that includes all known species of man who dealt with the earth sciences, such as geotechnical engineers, geophysicists, geochemists, and of course some lower subspecies such as geologists and engineering geologists.[1] Our specific task is to investigate a highly unique group of Geomen who had their centre of activity at approximately 60 ° North and 10 ° East on the planet Earth.

Our space-ship, the third of its kind, bears the name of this unique group of Geomen. The name was determined from fabric remains, evidently of work clothing, found embedded in glacial ice by a previous expedition to earth. The remains, which are shown below consisted of a strip of blue cloth and the 3 red letters, I, G and N, approximately 2 cm high, of long-fibre cotton on a white cotton background.

Since the original sequence of these 3 letters was not known, these clues were combined with all other known information about Geomen and a master computer was used to evaluate the most probable of the 6 possible permutations of these 3 letters. The results of this analysis, as shown in the table below, indicated conclusively that the most probable combination of these letters was GIN.[2] This finding led ultimately to the name of our space-ship, GIN LAB 3.

At our present velocity of 2750 km/min GIN LAB 3 will require about 30 minutes to reach the planet earth. It will be well for us to use this time to review the available background information we have on Geoman, so that we will be better prepared to carry out our work tasks when we do arrive at our destination.

Permutation analysis of Geoman fabric remains

Remains consist of 3 letters: I, G and N.

Possible permutations: 6   Permutations are:

No.	Permutation
1	I N G
2	I G N
3	N I G
4	N G I
5	G I N
6	G N I

Most probable combination (based on all available data) is permutation number: 5

GIN

1. The reader is advised not to take the author's classification seriously!

2. The true sequence is of course NGI which stands for the Norwegian Geotechnical Institute.

THE STORY OF MAN

Once upon a time life on the smallish planet called Earth was dominated by a living creature known as Man, and of all the manlike species who inhabited the earth only this one – homo sapiens – survived for any appreciable length of time.

Man's family tree took root at a time when conditions on the earth were not very well suited for rapid growth, and it wasn't until the early Pleistocence period that the tree started growing branches. During this geologic period of time we encounter for the first time such well known and socially respected family names as: Java man, Peking man, Neanderthal man, and Floresbad man. Their descendants in the late Pleistocene period were: Late Java man, Late Peking man, Cro-Magnon man, and Rhodesian man; who were the ancient ancestors of the entire human race, including Geoman.

Man differed from other forms of life on his planet in that;

- he walked upright,
- he had a thick skull,
- he had a large brain, and
- he was the first and only creature to be aware of his own evolving.

And as man assumed control over his own evolution;

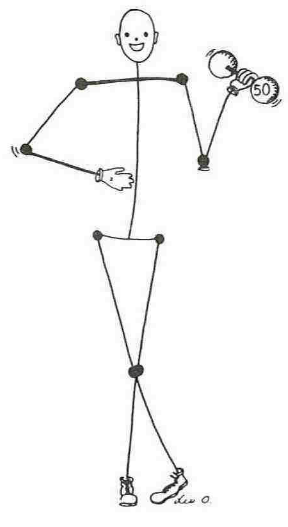
- he became more complicated and complex,
- he got taller,
- his skull got thicker,
- his brain got bigger,
- he developed efficient methods of communicating, and
- his ability to make tools improved.

The latter point is significant because the tools that man used are important to a study of his past in that they provide valuable clues to his existance and indicate the level of his culture. Our study of Geoman is very dependent on this fact.

THE APPEARANCE OF GEOMAN

In the process of evolution man reshaped his world and created a system of social development and cultural inheritance called civilization. As his civilization became more physically organized, man could afford to devote less time to matters of survival and more time to tasks that would improve his own well-being and that of his society. Consequently, with the rise of civilization some men could, and did, devote their entire adult lives to a study of their surroundings in order to improve the well-being of all members of their society. This trend started very slowly at first; but it soon developed at an accelerating rate. Before long the planet Earth became densely populated with a large number of specialists who dealt with individual professional topics such as economics, engineering, ski-waxing, oceanography, etc., and it is not surprising that as more and more specialists appeared on the surface of the earth, it became more and more difficult to find an area of specialization. As a result of this trend the topics of specialization became narrower in scope, less clear in concept and perhaps of less significance. Thus it came to be that Geoman appeared in the 20th Century as a subspecies of homo sapiens and a specialist in the so-called earth sciences.

Geoman was an individual; strong of body, quick of mind and rich in character. From a statistical point of view, Geoman would be classified an average man; however, in many ways he differed considerably from his fellow man. Above all Geoman



Geoman

was a happy man, who was profoundly interested in any and all things – he was even interested in his work!

Geoman appeared on the earth at a time when man's civilization had advanced to the point where man was starting to lose control over his own evolution. The first visible symptom of this state was that human beings began to suffer from a man-made illness called stress. In the beginning Geoman was immune to this particular disease; but he was afflicted instead with another form of stress – not a mental illness, but a measure of the internal state of affairs within the various materials and bodies that he dealt with. For Geoman, stress was an indicator of the equilibrium of a body or medium and a parameter he could use in his work to differentiate between good and bad, or success and failure. He devised a crude numerical scale to express the level of this differentiation. He called it *factor of safety*.

On this scale, a factor of safety of 1.0 was defined as the dividing line between good and bad or success and failure. From that time on Geoman became totally obsessed with this number.

Whereas other members of his society could not sleep well at night because of stresses associated with their way of life, Geoman could not get a good night's sleep unless he knew what the stresses were in natural materials, such as soil and rock, or man-made materials like steel and concrete. It worried him constantly. Geoman was not able to eat, sleep, drink, be merry or do anything in a relaxed state of mind unless he was reassured that the so-called factor of safety of everything around him was greater than unity.

Geoman had reason to be concerned for he had learned the hard way. From firsthand experience he knew all too well that if these material stresses got too high, mother nature would punish him quite severely and in direct proportion to the unbalance in stress. His structures would fall down or distort so badly they would become unserviceable, dams would fail or leak excessively, landslides would occur, and sometimes even large portions of his planet would literally quake and shake in protest. Frequently great loss of life was involved.

Through his own senses, Geoman was all too conscious of the consequences of high stress, for he could see, hear and feel the results directly. But only after the fact, never before. Until a failure condition occurred he was completely in the dark, as he could not perceive through his own senses how large the stresses were or how close they were to the critical equilibrium state at which mother nature would retaliate by initiating some form of punishment.

Man's social stress problems could be cured by means of a variety of pills, more-and-more free time, and by long periods of treatment with words administered by other specialists in a process called psychoanalysis. Unfortunately for Geoman, his stress problems were not solved quite so easily. Because he was not equipped with any human powers that enabled him to sense how critical his stress problem was, he seldom knew that he required treatment at all until it was too late. In order to cope with this unfavourable situation, Geoman used his natural intellect to develop ingenious mathematical methods and theories that enabled him to estimate stresses and compute factors of safety to two or three decimal places, depending on the importance of the project and the length of his slide rule or the cost of his services. In this way Geoman was able to deal qualitatively for the first time with these problems and thereby compensate partly for his inadequate senses. Parallel to his theoretical work, he learned to devise and use laboratory methods of analysis as a supplement to or as a means of verifying the results of his theoretical deductions. This helped but it was not enough.

For no matter how good his theoretical and laboratory methods were, the results were at best only intelligent estimates, and Geoman realized this. Consequently, in spite of his theoretical achievements Geoman still suffered from insomnia. Now he could not rest his body or relax his mind until he was able to confirm his new theories by direct measurement of what the real stresses were. To overcome this undesirable situation Geoman initiated an intense period of research and development aimed at producing instruments and artificial sensory devices that would enable him to determine directly what the state of stress was in his structures and within his media. This was the start of the evolution of Geoman's celebrated 7th sense.

Try as he could, Geoman found it either extremely difficult or even impossible to devise tools that could be used to measure all forms of stress directly. Devices for determining fluid stresses, such as porewater pressure in his media or fluid loading on his structures, were put into use soon thereafter as these were relatively easy to develop. For observations of other forms of stress he generally had to abandon all hope of observing these directly and instead rely on measurements of other parameters that would give him stress information indirectly.

Fortunately, it proved comparatively easy to develop ways of measuring relatively large linear and angular displacements. As a start Geoman capitalized on this fact and systematically used these measurement techniques to determine the distortions and movements of his structures and media. Through years of experience and guided by theoretical concepts he learned to interpret displacement data and use it as a basis for evaluating the stability of his structures and the performance of his works. As time went on, techniques of measuring displacements became more accurate and reliable, and eventuelly man developed experimental devices that enabled him to measure extremely small displacements or strains with sufficient accuracy that they could be used as a reliable basis for indirect determination of stresses.

These devices became known as strain gauges, and since they had such universal application they soon became the nucleus of Geoman's 7th sense.

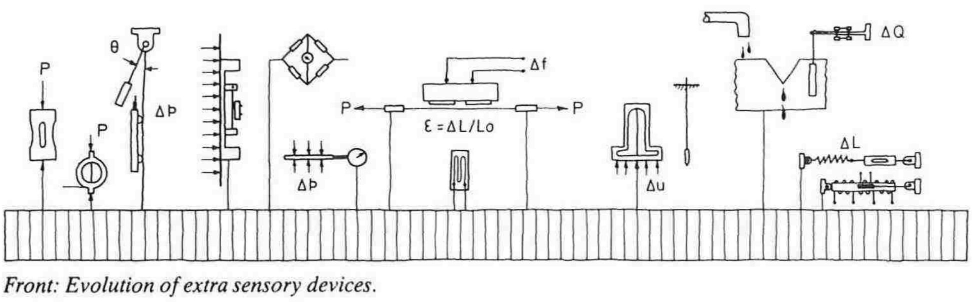
Strain gauges as well as all the other mechanical and hydraulic gadgets that Geoman developed were in effect extrasensory devices or tools that could be used to sense, quantify and convert information into a form that the human brain could detect and interpret. These tools were, in effect, the receptory organs of Geoman's 7th sense, and their rôle was in many ways similar to that of the human receptory organs which were fundamental to man's inborn senses. With tools of this kind Geoman was able for the first time to make quantitative measurements of many important physical parameters that he could not observe directly with his inborn senses. Since these devices functioned much in the same way as his natural senses, certain types of them were commonly referred to as 'sensors'. Collectively these devices were known as instruments and the art of using them was called 'instrumentation'.

GEOMAN DEVELOPES TOOLS FOR HIS 7'th SENSE

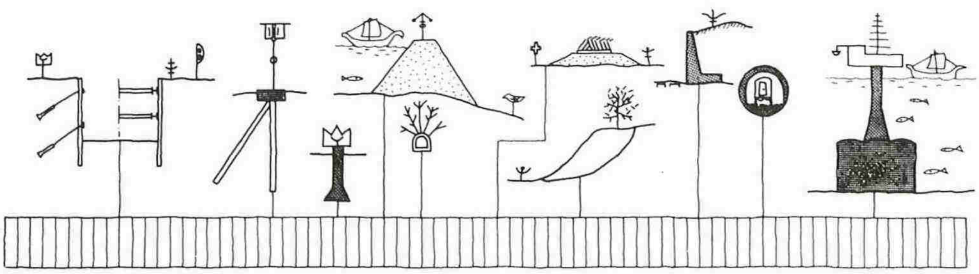
In recognition of the potential that these devices had in his field, Geoman entered into an era of intense tool construction wherein considerable time and resources were devoted to the development and production of the extrasensory devices he needed. This was an era that never really ended; for, by nature of the variety and complexity of his work, Geoman always had a need for his 7th sense and these tools in one form or another.

The tools that man has used in the past are important to historians in that they provide valuable clues to his existence and indicate the level of his culture. Since man's tools survived better than his skeletal remains, archaeologists and anthropologists have based much of their work and theory of the evolution of humanity on a study of prehistoric tools and the techniques of their manufacture. As far as we are concerned, there is little difficulty in finding evidence of this kind for a study of Geoman. At times he must have been a prolific tool maker, because the remains of these are found literally by the thousands all over the planet Earth.

Gin Lab scientists have had a difficult time trying to decipher the reimains of Geoman's tools, but some progress has been made in classifying them according to function and method of use. A major breakthrough in this work occurred with the discovery of a sequence of inscriptions carved on the



Front: Evolution of extra sensory devices.



Back: Areas of application.

Geoman's runic calendar (Anno 1953–1978) surface of a strange wooden object that Geoman used for transportation over snow covered areas. This piece of wood or ski, as it was called by Geoman, survived evidently because of a multicoloured – multilayered coating of an unknown waxlike presentative.[3] The pattern of the inscriptions found on this piece of wood has a striking resemblance to the primstav[4], which was a form of calendar that Geoman's ancestors used to keep track of the seasons of the year; thus, this relic which is shown in the preceeding sketch has been called 'Geoman's Runic Calendar or primstav.

The inscriptions on the front and back of this runic calendar provided the first clues that enabled Gin Lab scholars to link function and type of device to method of use and type of parameters measured. The inscriptions on the front are believed to portray the evolution of Geoman's extrasensory devices; whereas on the reverse side the inscriptions are thought to represent the types of projects or applications where Geoman used these devices. Gin Lab scholars have concluded from these inscriptions that the following physical quantities were of primary interest to Geoman:

- force,
- pressure,
- linear displacements,
- angular displacements,
- stress and strain, and
- fluid flow.

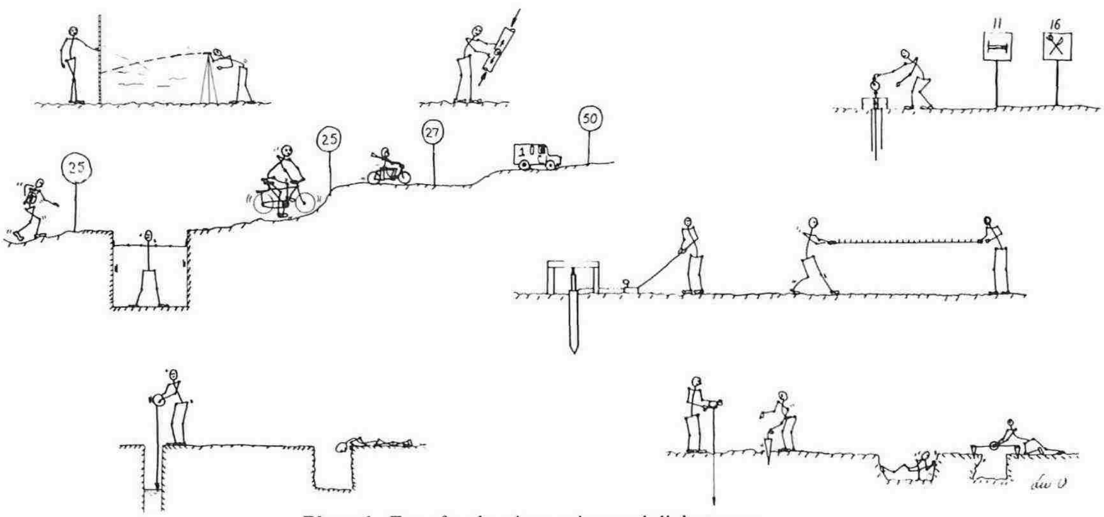
Evidently this information was all that Geoman needed to solve the majority of the problems that he was confronted with, when he was engaged on projects of the type depicted in symbolic form on the reverse side of his runic calendar.

The first tools made by Geoman were extremely crude. They consisted for the most part of simple mechanical and hydraulic devices that were fabricated of an odd combination of nuts, bolts, bailing wire, springs, iron pipe and bits and pieces of tubing. However, as Geoman evolved and became more complex and complicated, so did his tools. Crude hand-operated mechanical devices that were time consuming and cumbersome to use were gradually replaced by sophisticated electro-mechanical devices that could be sensed remotely and monitored automatically. The development and improvement of these devices was a continuous process. Nevertheless, Gin Lab scholars have identified five distinct stages in the evolution of Geoman's extrasensory devices. These are defined as follows.

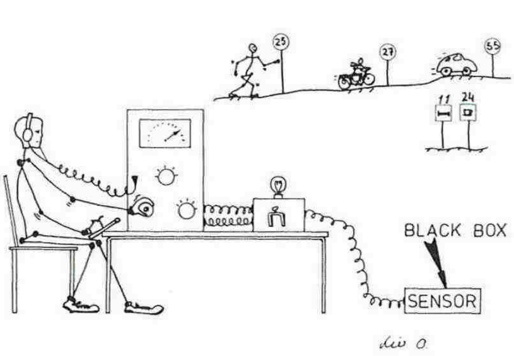
Phase 1. Era of rods, pipes, wires and dial gauges.
Phase 2. Evolution of gadgets and black boxes.
Phase 3. Geoman learns to digitize information.
Phase 4. Geoman learns to use recording equipment.
Phase 5. Era of automated data acquisition.

The level of technology attained by Geoman during each of these five stages of development is indicated in the following sketches. The dating method used by Gin Lab scholars to reconstruct the chronologic progress shown in the figures was based on a detailed study of expense accounts submitted by Geoman for travel and accomodations (see notes in the figures). Because Geoman travelled extensively, an enormous number of these documents were discovered in the ruins of the local *ligningsvesen*[5] on a previous expedition to the planet Earth.

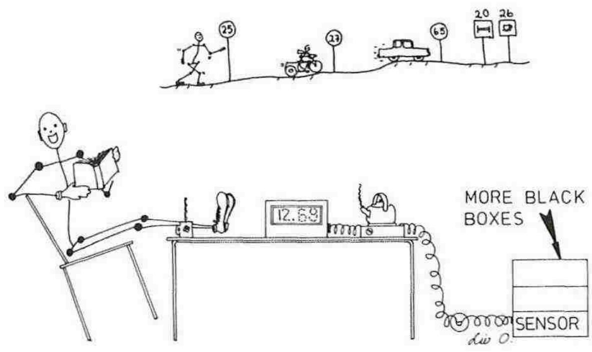
3. Refers to ski wax – a substance Norwegians use in large amounts.
4. The primstav was a form of calendar used by Nordic people up to the 16th century. It consisted of a wooden stick marked with lines for each day of the year, days of the week were denoted by letters of the runic alphabet, and special symbols were used to indicate holidays.
5. Tax office.



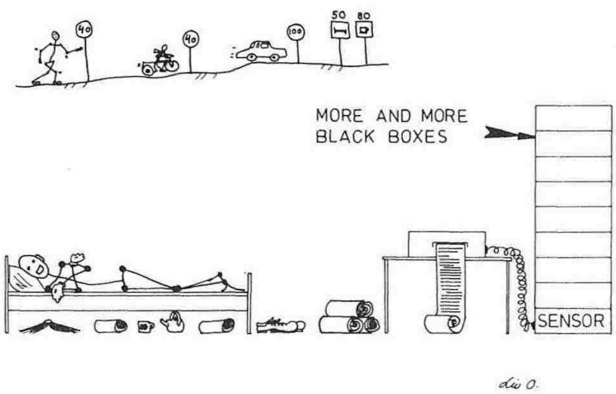
Phase 1. Era of rods, pipes, wires and dial gauges.



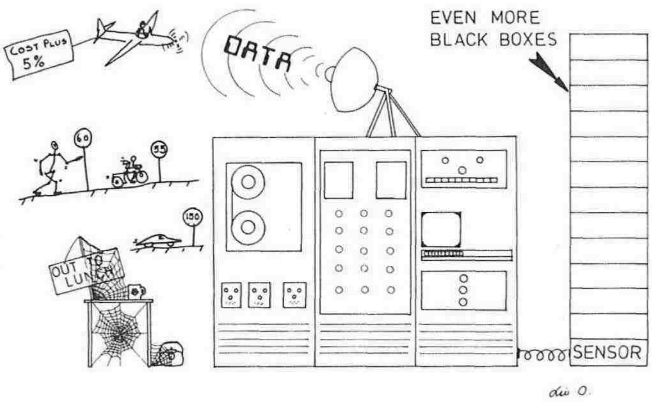
Phase 2. Evolution of gadgets and black boxes.



Phase 3. Geoman learns to digitize information.



Phase 4. Geoman learns to use recording equipment.



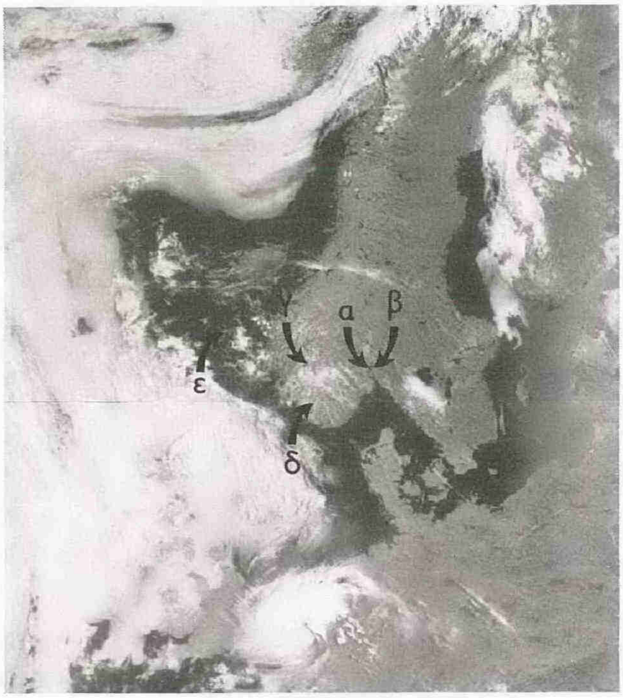
Phase 5. Era of automated data acquisition systems.

Author's notes. The highway sign posts in the sketches indicate the official reimburseable rates for travel and per diem during the indicated time eras. The circular shaped signs denote cost of travel, in øre per km, for the indicated forms of transportation. The square shaped signs denote the allowance for food and lodging in kroner (100 øre) per day.

EVIDENCE OF GEOMAN'S ACTIVITIES

Many examples of Geoman's works have survived the passage of time because they were constructed wholly or in part of materials as durable as the earth itself. Thus, it is not difficult to find remains of his activities for study.

Gin Lab scientists have used a new deep penetrating X-ray camera to scan several areas of the earth where it is known that Geoman had been particularly active. A number of activity sites containing interesting ruins and remains of material objects have been discovered by these X-ray surveys. Some of these discoveries are of such unusual character that they have been designated as Test Sites for further study, and archaeological excavations at these sites are already in progress. Five of these have already been studied in detail by the crew of GIN LAB 2 on the last expedition to earth. The locations of these sites are indicated on the following satellite photograph. Visits to these 5 sites will be included in our mission to earth.



Location of test sites

Test Site Alpha. In the ruins of an old barn in an area formerly known to earthmen as Lommedalen.[6] Remains of a unique rocket-like device.

Test Site Beta. At the tip of the Oslofjord. Remains and evidence of an unusual manmade hole in the ground.

Test Site Gamma. Under 500 m of water at the bottom of the Hardangerfjord. Remains of a most unusual and puzzling character.

Test Site Delta. Between two steep valley slopes in the south west part of this land area. Remains of an extremely large burial mound.

Test Site Epsilon. Approximately 300 km from shore. Unusual remains of concrete and steel on the sea floor.

During the next few minutes, while the Gin Lab 3 crew is readying our space craft for landing, we will review the background information we have for each of these test sites.

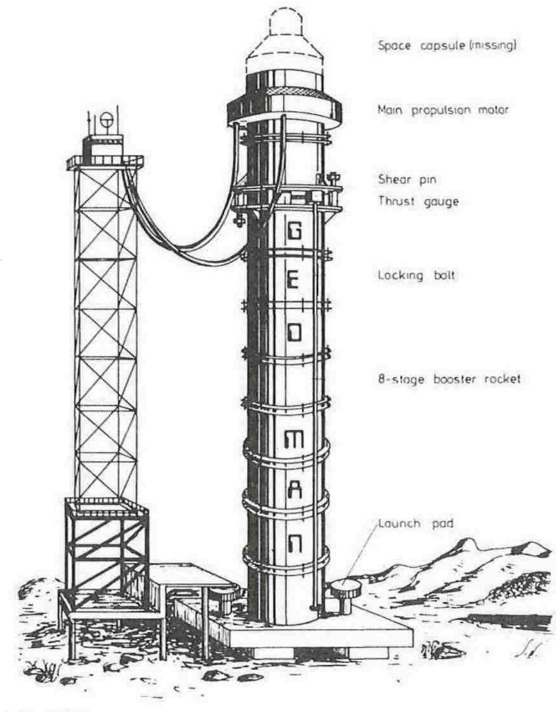
TEST SITE ALPHA

In the early days of Geoman, men on earth were constructing rockets for exploration of space and for the destruction of each other. There is firm evidence that indicates that Geoman was also interested in rocket construction. At Test Site Alpha, the ruins of and old barn that was apparently used by Geoman for storage of top secret equipment, archaeologists have discovered a number of large-diameter cylindrical objects that have a striking resemblance to crude rocket shells.

An artist's conception of what Geoman's rocket looked like can be seen in the following sketch.

This unusual 8-stage rocket had a chain driven hydraulic propulsion motor. The space capsule or payload section was never found or identified, so it is virtually impossible to determine what the rocket was to be used for.

I appears, however, that Geoman was not a very good rocket engineer. Whereas other men's rockets were launched upwards and at great speed, Geoman's rocket were apparently unknowingly assembled upside down. For they never got off the ground. Instead, they burrowed into the gound, and the more propulsion force Geoman applied, the deeper they penetrated. There is some conflicting evidence on this matter, however. There have been reports of the discovery of several unusual impact craters near the ancient cities of Göteborg and Stockholm. Gin Lab military experts believe these could have been caused by Geoman's rocket device. If this is true,



Test site Alpha

6. Small valley to the west of Oslo.

then it is the first evidence on record that indicates Geoman was engaged in rocket warfare with his big brothers directly across his eastern border.

Geoman's rocket was equipped with a number of complex devices for sensing forces, stresses, pressure, linear motion and tilt, but since these rockets apparently never got off the ground, it is unlikely that he had a chance to use these devices.

TEST SITE BETA

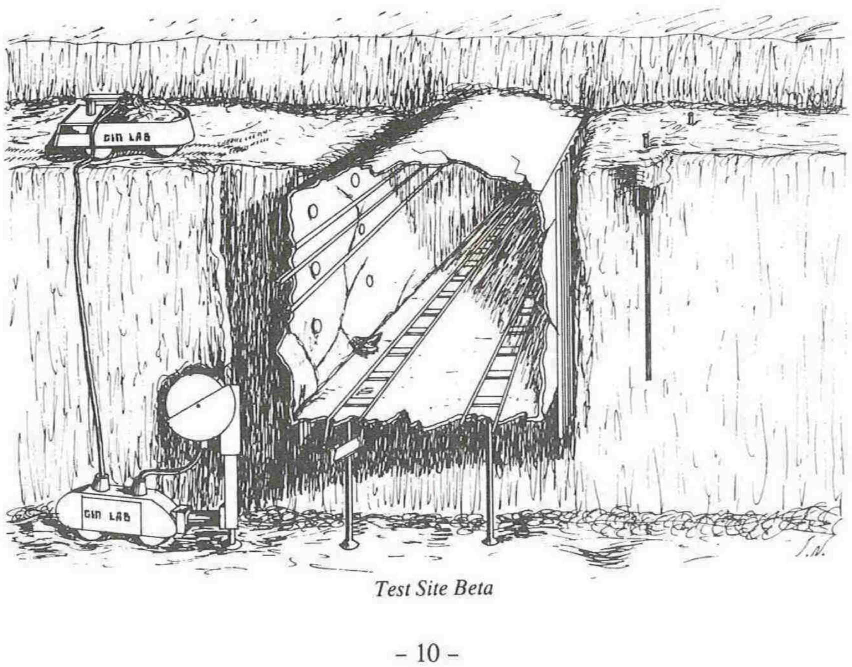
Evidence of man-made excavations, like the one at Test Site Beta, are commonly found on the planet earth. Evidently excavations played a key rôle in man's efforts to make use of his planet as a source of raw material and as a place to live in comfort. For this reason one of Geoman's work tasks was to develop safe and economical methods of making excavations in the ground for extracting minerals and other forms of natural resources or for locating buildings, utilities, subways and the like.

This seemingly simple task was in reality often quite difficult to accomplish. Sometimes it couldn't be done at all. For in many areas where Geoman lived the natural ground was so weak that it was virtually impossible to make an excavation more than a few meters deep withourt upsetting the critical stress balance in the ground and initiating a failure. Each and every excavation that did fail represented a blackmark against Geoman's reputation as a specialist on these matters. Accordingly, and if for no other reason than to protect his own reputation, Geoman devoted much time and energy to devise ingenious methods of making failure-proof excavations of all sizes and shapes.

Geoman recognized that as long as nature's forces were kept in equilibrium, excavations could be made safely without great difficulty. And, if he knew the magnitudes of the forces, stresses and deformations that were involved, he could take these into consideration in his design procedures and propose a safe and economical method of making excavations.

In the beginning, excavations were a source of worry to Geoman for two main reasons. First, he did not have a tried-and-proven method of calculating basic design parameters, such as forces, stresses and deformations. The best he could do was to estimate these on the basis of theoretical considerations or by extrapolating results of small model tests. Secondly, during construction of an excavation Geoman could not establish what the actual factor of safety was for the excavation at any given stage of construction. With his own senses he had no way of determining how close or how far the project was from a failure condition.

To overcome his own shortcomings Geoman embarked on an extensive program to develop suitable extrasensory devices that would enable him to measure quantitatively the pressures, stresses, forces



Test Site Beta

and deformations that were so important to an understanding of the excavation problem. These new tools were in due time developed and Geoman used them frequently and with great enthusiasm. They became tha backbone of his 7th sense which he could use to measure the parameters that he knew so little about. Through this pseudo-7th sense, Geoman had for the first time a means of construction control by which he could assess the safety of an excavation as it was being carried out. In addition these extrasensory devices provided him with valuable case-history records that were used to verify or modify and improve design procedures for excavations.

Remains of man's excavations are everywhere, but the remains of the one at Test Site Beta are interesting from the point of view of method of construction and the use that Geoman made of his pseudo-7th sense. An artist's conception of this excavation together with the structure built in it is shown below.

Gin Lab scientists have detected no less than 80 extrasensory devices and miscellaneous measuring points at this site; consequently, this excavation must have been of great concern to Geoman. One interesting point should be mentioned. Archeologists who have studied the remains have found unusual evidence that is thought to be a high water mark inside the bounds of the excavation. This indicates that the excavation was once filled with water; but it is not known if this was done deliberately or if it was accidentally flooded. In any case it is known that Geoman called this particular excavation *'Vanngrøft'*.[7]

TEST SITE GAMMA

One of the most baffling discoveries made to date with the X-ray scanning camera is a cubical-shaped object found deeply embedded in the sediments, beneath 460 m of water, in the inner Hardangerfjord at latitude 60.4 ° North and longitude 6.8 ° East.

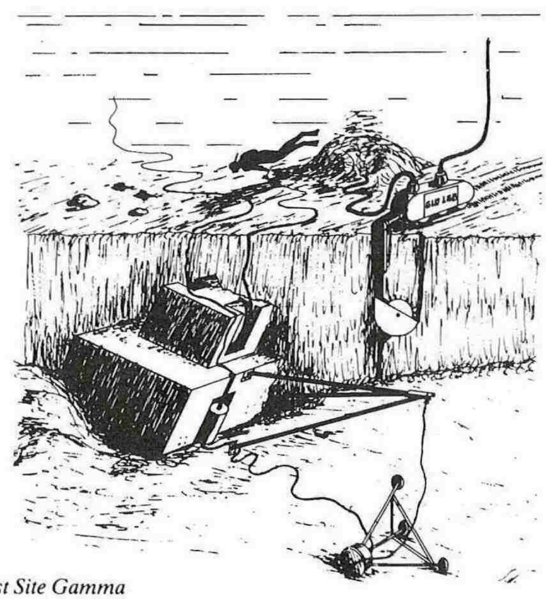
From images obtained with the X-ray camera Gin Lab artists have prepared a sketch of this strange object as shown below.

As can be seen, it is block-like in appearance and about 4.5 × 4.5 × 2.0 m in size. For comparison purposes, an average Gin Lab diver is drawn to scale in the figure. You will also note in the sketch that there is a long umbilical cable attached to the block. This cable trails off some 700 m in the distance to a remote point on shore. Gamma-ray density tests indicate that the block is made of very dense concrete and magnetic surveys seem to indicate that the aggregate used in the concrete is iron ore. Computations show that the density is probably about 4.0 t/m^3. If this is true, then this relatively small block must weigh at least 130 tons submerged.

X-ray data show clearly that there is a metal cylinder embedded inside the concrete block and attached to the end of the umbilical cable. It is believed that this cylinder houses a number of sensing devices used by Geoman in his work.

What is unusual about the discovery is its location – alone at the bottom of the fjord, miles from any known areas of former civilization. Gin Lab scientists have not been able to come up with any realistic explanation of its purpose or of what Geoman intended to accomplish with this block at the location where it was discovered. Consequentially, scientists have concluded that the block must have accidentally fallen overboard from a barge or ship during transport and plunged to the bottom of the fjord to be lost for all time.

This is the only palusible explanation as to how it ended up at its present location. If this is true, then it represents another documented example of one of Geoman's projects that failed because he neglected to take into consideration all the little details that are important to the execution of a project involving instrumentation.



Test Site Gamma

7. Literally 'Water-filled trench'.

TEST SITE DELTA

Some of the most interesting and informative remains of mankind are the burial mounds that human beings constructed to dignify and honour their dead. Since their size and shape, method of construction, and artifacts placed in them varied throughout the generations of mankind, these burial mounds provide valuable clues to man's customs and the level of his culture at the time they were built.

Geoman, like his fellow man, also constructed burial mounds; but his burial mounds were in many ways quite different from those built by his predecessors or his successors.

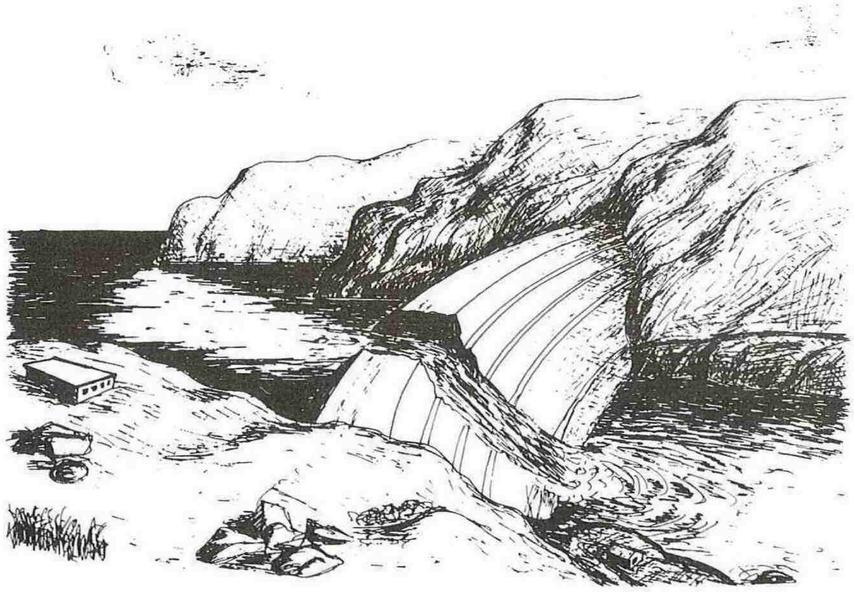
First of all they occur in great numbers, usually in very remote areas, and always in the proximity of rivers and lakes. In size they vary anywhere from 10 m to 130 m in height. In shape they can best be described as 2-dimensaional strip mounds. Although the majority of Geoman's burial mounds are found in mountanous regions they have been discovered in low lying areas as well. Regardless of size or location they are always built across a valley or river in such a way that they impound vast amounts of water but on one side only. Gin Lab psychologists who have studied the behaviour of Geoman have concluded that to Geoman water represented a symbol of power, cleanliness and life. This latter connotation of life is further substantiated by the Latin word that Geoman used to express his feelings about a particular type of water-like substance, which he called 'aquavit'[8] ot literally water of life. Whereas earlier man placed a supply of food or tools and ornaments in his burial mounds, Geoman made sure that there was indeed an ample supply of lifegiving water on hand to guarantee him power, cleanliness, and everlasting joy and happiness in the world thereafter.

As seen on the artist's sketch below, the partially eroded burial mound at Test Site Delta is a typical one. It has a maximum height of 129 m, maximum base width of 400 m, and comprises a total volume of 4,700,00 m^3. Dating methods indicate that it took nearly 4 years to build. Photographs taken with the penetrating X-ray camera show that it was meticulously constructed in very thin layers of natural material segregated in zones according to a well defined geometrical pattern. As always, the largest materials are found in the outermost zones and particle size gets progressively smaller as one approaches the centre of the mound from either side.

Geoman's burial mounds were constructed in accordance with exacting specifications developed on the basis of empirical and theoretical design considerations. But judging from the large number of extrasensory devices built into these structures, Geoman must have been a bit nervous about their performance and his design procedures. In order to put his mind to rest, he was forced to rely heavily on the use of his 7th sense to provide him with the information needed to assess the safety of these structures. The mound at Test Site Delta, for example, contains no fewer than 123 sensors for monitoring pressure or strain, and over 158 reference points on the surfae and within the body for monitoring deformations.

There is one fact that Gin Lab scientists have never been able to explain. So far, no one has found any skeletal remains in Geoman's burial mounds.

8. Strong alcoholic drink that it well known in Scandinavia.



Test Site Delta

TEST SITE EPSILON

In the beginning man's ability to do work was determined by the strength of his own muscles and the strength of the animals that he could train to do useful work. When their combined efforts became insufficient to meet the needs of his ever growing society, man learned out of necessity to construct machines. From that time on, man's ability to do work was limited only by the size of the machine he could produce. But these machines were grossly inefficient and as a result they consumed far more energy than could be extracted from them in the form of useful work. Ultimately, man's never-endring demands for power lead to a severe shortage of energy on his planet.

As man explored the earth for new sources of energy he selected first of course those areas where these resources could be obtained easily and at little cost. Eventually, however, as he used more and more energy he was forced to look in every conceivable place on his planet for new sources, including in the vast areas beneath the oceans. In this connection, geophysicists and geologists using a variety of extrasensory devices, that comprised their 7th sense, were able to locate vast amounts of oil and gas beneath the sea floor – much of it in it the sea adjacent to the land inhabited by Geoman.

An entirely new technology was required to extract these new found sources of energy and wealth from below the bottom of the sea. Stationary platforms of tremendous size and strength were required to support drilling and production equipment needed to develop these oil fields. Geoman played an important role in this pioneering work.

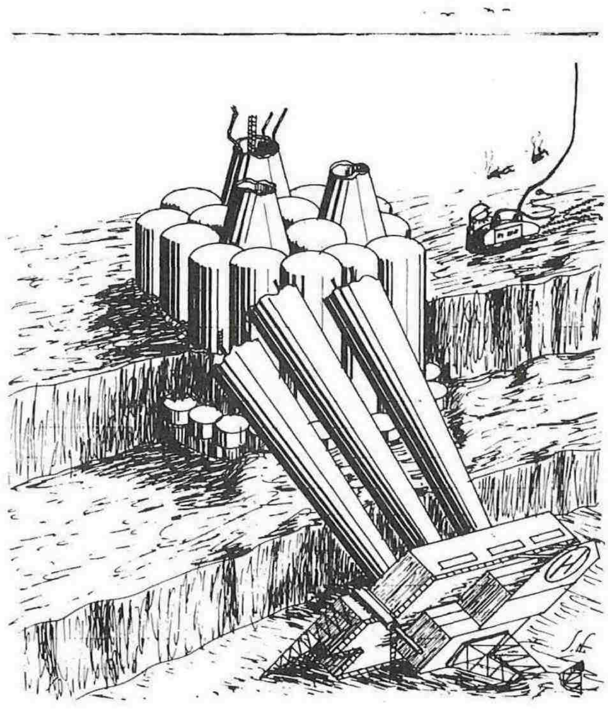
The land inhabited by Geoman was not rich in natural resources; but sand, gravel and raw materials for making cement were available in vast amounts. For this reason engineers in this part of the planet had a long tradition of constructing major structures of reinforced concrete. Thus it was only natural that concrete be used as well for the offshore structures needed to produce oil. Since it was virtually impossible to use conventional construction methods to build or assemble concrete structures far from land out in the deep and stormy waters of the North Sea, a new construction procedure had to be found. The construction concept that was eventually put into action was ingenious, fascinating and highly sucessful. These mammoth structures were first built as floating units in sheltered waters near the coast, then fitted out with complete oil drilling and production facilities, and finally towed out to the designated site offshore and set on the sea floor with a precision and daring that resembled in many ways the first manned lunar landings that took place just a few years before. Gin Lab oceanographers have discovered the ruins of a number of these concrete structures south of the meridian 62° North; for some unexplainable reason none have been found north of this line.[9] An artist's sketch of the partially demolished ruins of one of these structures located about 300 km from land in 150 m of water is illustrated below. It is believed that this structure was intentionally demolished, when the oil reserves beneath it became depleted, but only after all attempts to refloat and relocate the structure at another site failed.

These structures were known to earthmen as Gravity Base Structure, or simply GBS, because their resistance to environmental loading was due entirely to their sheer weight and size. The foundation design of these complex structures was entrusted to Geoman, who assumed this challenging responsibility with great vigor.

This was not an easy task, because these structures differed considerably from the conventional structures that man had been constructing on land for centuries. The basic concept, the method of installation, the applied loads and service requirements were such that Geoman could not rely entirely on the well known and traditional design procedures used for conventional structures.

Thus, new analytical methods and laboratory procedures had to be developed in order to design and predict their behaviour. And above all it was gen-

9. The decision as to when, if ever, to start exploratory drilling for oil north of the 62° meridian in the North Sea was an issue of deep political controversy in Norway at the time of this lecture (1979).



Test Site Epsilon

erally recognized that these structures had to be extensively monitored to insure that neither the structure nor the underlying soil was damaged during installation on site, and to verify that the behaviour of the completed facility was in accordance with design predictions. Never before in the history of Geoman had his 7th sense and all his extrasensory devices and gadgetry become so important to him.

Gin Lab divers who have studied the demolished structure at Test Site Epsilon have identified broken multicore platform cables that Geoman used for electrical hook-up of his extrasensory systems. A direct count of the total number of conductors in these cables indicates that Geoman had at least 191 sensing devices on this structure. Spot tests showed that many of these devices are still operative in spite of their age and the condition of the structure.

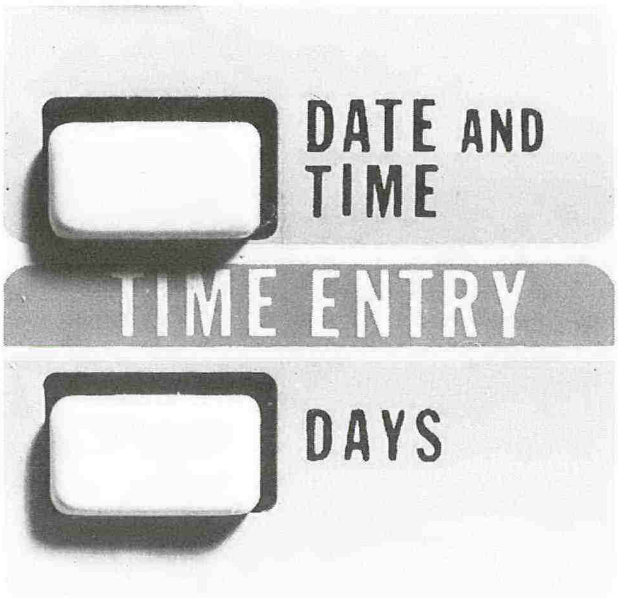
EARTH LANDING AT TEST SITE ALPHA

Ladies and Gentlemen, it is very tiring to travel in a cramped space ship like Gin Lab 3 for such a long time. We are about to land on the planet Earth at Test Site Alpha, and during landing it will be more compfortable if we raise the center of gravity of our space craft a little bit. Therefore, I ask that you all stand up now and take a stress break for about 30 seconds while the crew bring the ship down to earth.

(30 second Pause.)

Ladies and Gentlemen, we have arrived safely at Test Site Alpha, please be seated. As you recall Test Site Alpha was the site where Geomans rocket-like device was discovered.

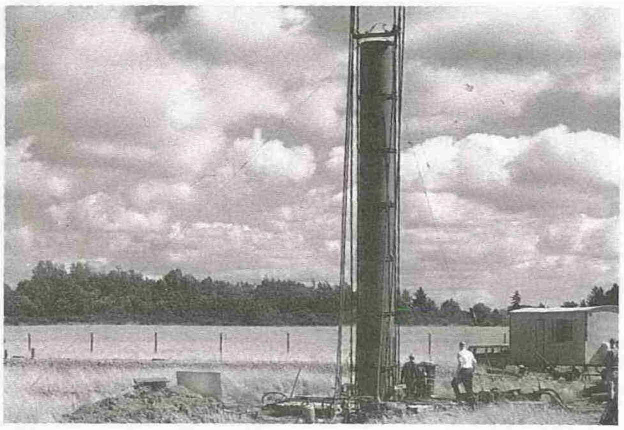
In order to find out what really happened at Test Site Alpha we will use our newly developed retrograde time-programming device to reset our current terrestial time reference axis to the actual year that Geoman was active at this particular site.



ANNO 1967

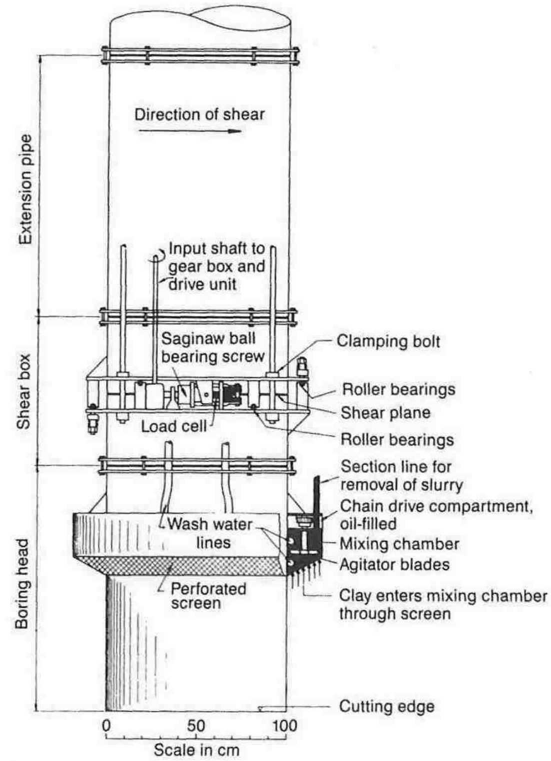
Test site Alpha revisited anno 1967

Ever since it was founded in 1953 the Norwegian Geotechnical Institute has devoted considerable research effort, both in the field and in the laboratory, to the determination of the shear strength of the soft marine clay deposits commonly found in Norway. Most of the knowledge regarding the in-situ shear strength of this clay has been obtained by use of the standard field vane boring. The desire to both supplement and verify the findings obtained with the field vane ultimately resulted in the construction of an unusual piece of research equipment for carrying out large-scale in-situ direct shear tests. When completely assembled this apparatus had a striking resemblance to a medium sized rocket. The apparatus was in reality a gigantic self-boring sampling tube that trimmed out a vertical core of undisturbed clay, one meter in diameter, as it borrowed into the ground. When a shear test was desired the boring process could be stopped and the clay core within the device sheared in simple undrained shear. Shear tests could be carried out down to a depth of 12 m.



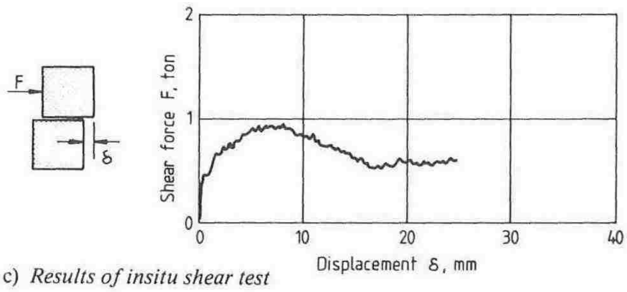
a) *Insitu shear device on location*

The principal features of the device are shown on the drawing below. The device consits of three main sections: a boring head, a 'shear box' and a series of extension cylinders. The function of the boring head is to trim out the cylindrical core of undisturbed clay and to remove the material around the periphery of the apparatus to form an annular space. As the device penetrates into the ground, the clay directly below the protruding section off the boring head is forced through the perforated screen into the mixing chamber. In the mixing chamber the clay is reduced to a slurry under the combined action of high pressure water jets and 24 mechanical agitators which are equally spaced around the mixing chamber. The agitators are activated by a sprocket chain driven by a hydraulic motor. The clay slurry is removed by suction pumps and the annular space above the boring head between the apparatus and the sides of the bore hole is filled with water to stabilize the hole.



b) *Details of shear apparatus*

The two halves of the shear box are clamped together during boring operations. When these clamps are released the upper half of the shear box can be translated, up to 5 cm, relative to the bottom half and in the process the clay core inside is sheared on a horizontal plane as illustrated in (c) below.



c) *Results of insitu shear test*

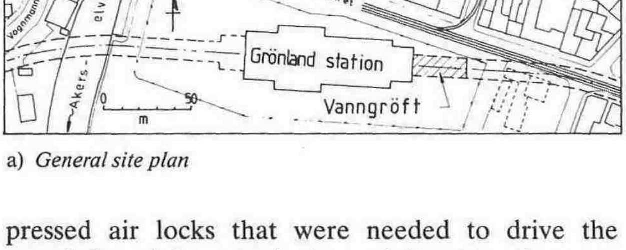
The force necessary to shear the clay core is developed by mechanical means and controlled from the surface. The shear force and displacement are monitored by specially designed instruments mounted on the shear box. Other instruments are used to measure verticality of the apparatus and the normal force on the top part of the shear box.

This example, unusual as it is, illustrates the potential that instrumentation has to improve our methods of in-situ testing and carrying out site investigations.

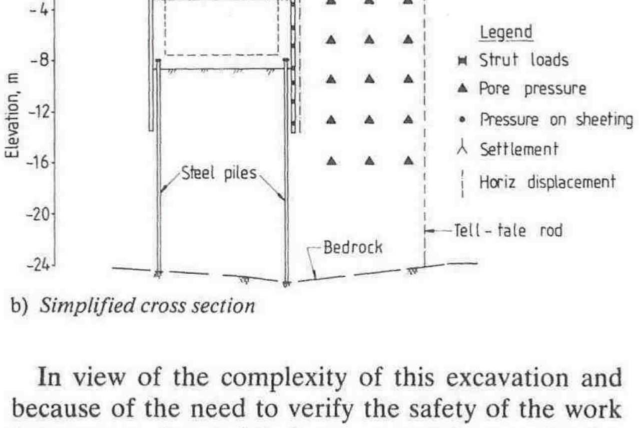
Reference: DiBiagio, E. and G. Aas (1967) "The in situ undrained shear strength measured on a horizontal failure plane by large-scale direct shear tests in quick clays". Geotechnical Conference Oslo 1967 on Shear Strength Properties of Natural Soils and Rocks. Proceedings, Vol. 1. Also publ. in: Norwegian Geotechnical Institute. Publication, 76.

Test site Beta revisited anno 1959

Construction of the eastward extension of the Oslo subway system provided an opportunity to carry out a number of extensive full-scale monitoring programs to study strut loads, earth pressures, and ground movements associated with deep excavations in soft clay. One important case studied was the excavation required to construct the first section of double track tunnel to the east from Grønland Station. This 30 by 11 by 11.5 m deep excavation was made for the specific purpose of installing the compressed air locks that were needed to drive the remainder of the tunnel. A special construction procedure had to be developed because at this location the soil was too soft to allow the excavation to be made to full depth as a simple open cut without risking a bottom heave failure. Furthermore because of the thickness of the clay deposit it was not feasible to improve the stability of the excavation by driving sheet pils to bedrock to close off the bottom part of the excavation. In order to prevent a bottom heave failure the excavation was flooded with water before the final 5.7 m was excavated. For this reason the excavation was referred to locally as *Vanngrøft* or 'water-filled trench'.



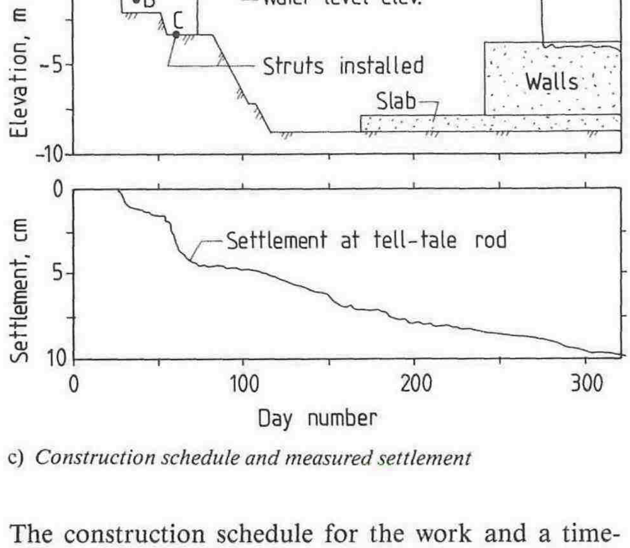
a) *General site plan*



b) *Simplified cross section*

In view of the complexity of this excavation and because of the need to verify the safety of the work in progress, it was felt that an extensive monitoring program was justified. The instrumentation program was quite substantial when one takes into consideration the time at which the work was carried out. It inluded:

9 load cells to monitor strut loads,
23 earth pressure gauges on the sheet piles,
8 water pressure gauges on the sheet piles,
19 piezometers in the natural ground,
18 settlement reference points,
1 tell-tale rod type settlement gauge,
1 heave gauge in the excavation, and
2 inclinometer casing.



c) *Construction schedule and measured settlement*

The construction schedule for the work and a time-settlement curve for the tell-tale settlement gauge are shown above, (c). After completing the first excavation stages and installation of the three-level bracing system in the dry, the excavation was flooded and excavation continued using grabs and divers working with jetting nozzles to clean along the sheeting and beneath the struts. In the figure the stabilizing effect of the water can be seen by the marked reduction in settlement rate after the excavation was flooded. As the work continued, field measurement data indicated that the excavation could proceed to the final depth without installation of a fourth level of struts that had been included in the original design of the bracing system, and this was done.

This example illustrates a situation where field instrumentation has been used to obtained information needed to assess the safety of a construction project while the work is in progress. In this case the measurement program also contributed to a significant savings in time and money in that the fourth level of struts was found to be unnecessary.

Referance: DiBiagio, E. and B. Kjaernsli (1961). "Strut loads and related measurements on Contract 63a of the Oslo Subway". International Conference on Soil Mechanics and Foundation Engineering, 5. Paris 1961. Proceedings, Col. 2. Also publ. in: Norwegian Geotechnical Institute. Publication, 45.

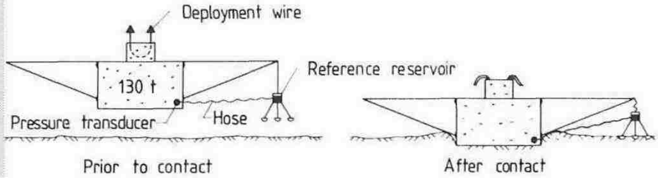
Test site Gamma revisited anno 1974

One of the principal factors that makes highway construction complicated in many parts of Norway is the difficulty in crossing the numerous deep fjords. One possible solution to this problem that has been evaluated is the construction of submerged tunnels or 'rørbruer' as they are called in Norwegian. These buoyant structures would span across the fjord and be held down by a series of cables and anchors.

In 1974 a full scale test was carried out to study the construction, installation and maintenance of a suitable concrete anchor block and cable assembly. The test provided as well an opportunity to monitor the settlement and tilt of the block after it was placed on top of the soft sediments at a depth of 460 m. The test site was in the Hardangerfjord at the location of a proposed crossing for the main highway between Oslo and Bergen.

a) *Anchor block prior to launch*

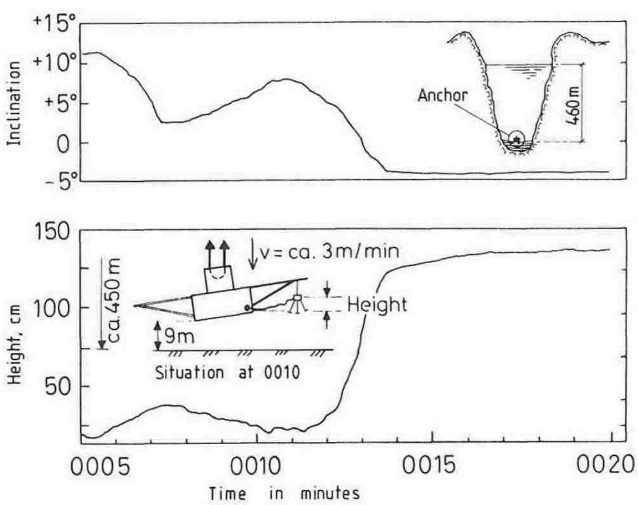
The anchor block was 4.5 by 4.5 by 2.0 m high and had a submerged weight of 130 tons. Iron ore was used as aggregate in order to increase the density of the concrete. The block was instrumented with a biaxial inclinometer to measure long-term tilt as well as the attitude of the block when it first contacted the surface of the sediments. A second instrumentation system was specially designed to monitor the settlement and penetration of the block relative to a point 5 m from one edge. The arrangement of the hydraulic settlement measuring system is shown in (b) below.



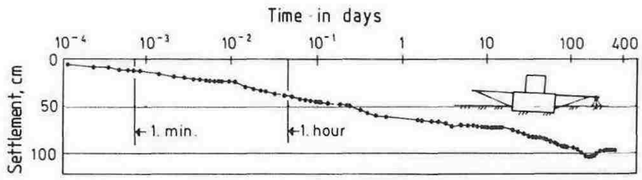
b) *Hydraulic system used to measure settlement*

The anchor block was built nearby on the sloping shore of the fjord. It was constructed in a horizontal position on top of a concrete foundation skid as shown in the photograph. During the launch the block and skid were first pulled out by a supply vessel to a depth of about 10 m, then the block was lifted off the skid and suspended from the stern of the ship, transported to the final location and lowered carefully to the bottom. A 700 m long signal cable connected to the anchor was run to shore for monitoring the instruments.

Some of the measurement data is given below. In (c) the measured inclination and relative height of the hydraulic reference reservoir is shown just prior to and during initial contact, and in (d) the entire measured settlement curve is shown. Measurements were terminated after approximately one year. At the end of this period the data indicated that because of the large settlement that had occurred, the arm protruding from the anchor block came in contact, with the 3-legged support for the refernce reservoir and tipped it over.



c) *Measurements at 'Touch-down'*



d) *Measured settlement*

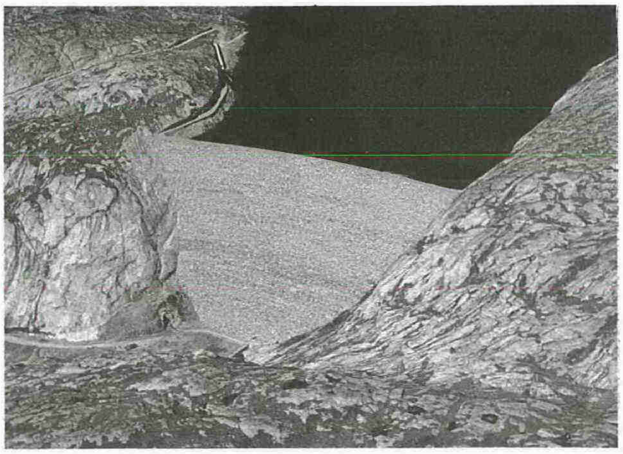
This full-scale test illustrates a situation where field observations that would otherwise be impossible to obtain were acquired through the use of remote reading instruments.

Reference: Flaate, K. and N. Janbu (1975). «Grunnundersøkelser på 500 meters sjødyp». Nordisk Geoteknikermøte, København 1975.

Test site Delta revisited anno 1976

The Norwegian approach to dam instrumentation has been to concentrate instrumentation on dams that have an unusual problem, or those that have design features which deviate significantly from existing dam types, or those that represent the first of a new kind or class of dams. These structures are then extensively instrumentated, in particular if it is anticipated that a number of similar structures will be built in the future.

The instrumentation case study referred to as Test Site Delta is Svartevann Dam, an earth-rockfill dam with maximum height of 129 meters, crest length of 400 meters and a total volume of 4.7 million cubic meters. Svartevann Dam was extensively instrumented because at the time of its conception, in the early 1970's, it differed significantly from existing dams in that its height was forty percent more than the highest existing dam in Norway. It was also the first of a number of rockfill dams of comparable height that were being planned for construction during the 1970's and 1980's.



a) *Svartevann dam*

The dam has a moraine till core, sand filters, fine-grained rockfill transistion zones and coarse rockfill shells, all placed and compacted in layers. The dam which is a part of the Sira-Kvina Development in south western Norway was completed in 1976.

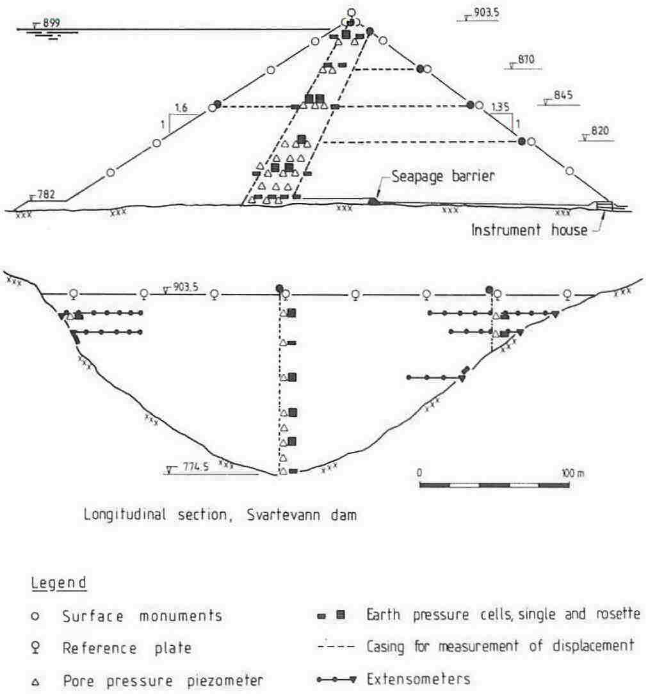
The instrumentation program for Svartevann Dam was designed to provide measurements of the following parameters: (1) displacements of the surface and within the body of the dam, (2) seepage through the core, and (3) internal stresses, i.e., pore water pressure and total earth pressure in the core and filter zone. The instrumentation comprises altogether 141 surface monuments, 8 settlement reference plates, 8 inclinometer casings for monitoring displacement and a total of 123 electronic sensing devices.

Horizontal and vertical deformations of the crest and support shells were determined by geodetic surveying the 149 surface monuments and settlement reference plates from six geodetic survey stations. Internal deformations were measured by means of strings of remote reading extensometers embedded in the dam and with the use of inclinometers and settlement devices that were used to survey special casings installed in the dam.

To measure leakage through the dam a barrier was constructed across the valley floor to impound and divert seepage water to a weir station at the downstream toe.

Altogether 30 pore pressure piezometers were installed in the dam to monitor construction pore pressures and the gradients across the core during operation of the dam. A total of 60 instruments were installed for monitoring soil stresses in the core and filter zones. Near the right abutment and crest where tensile stresses may occur, and in the region of core-shell stress transfer the instruments were placed in rosette groups to permit determination of the principal stresses and directions.

In this example, instrumentation has been used for construction control, to monitor the performance of the dam, and to obtain information that can be used for improved design of future dams.



b) *Details of instrumentation*

Reference: DiBiagio, E., F. Myrvoll, T. Valstad and H. Hansteen (1982) "Field instrumentation, observations and performance evaluations for the Svartevann dam".
International Conference on Large Dams, 14. Rio de Janeiro 1982. Transactions, Vol. 1. Also publ. in: Norwegian Geotechnical Institute. Publication, 142.

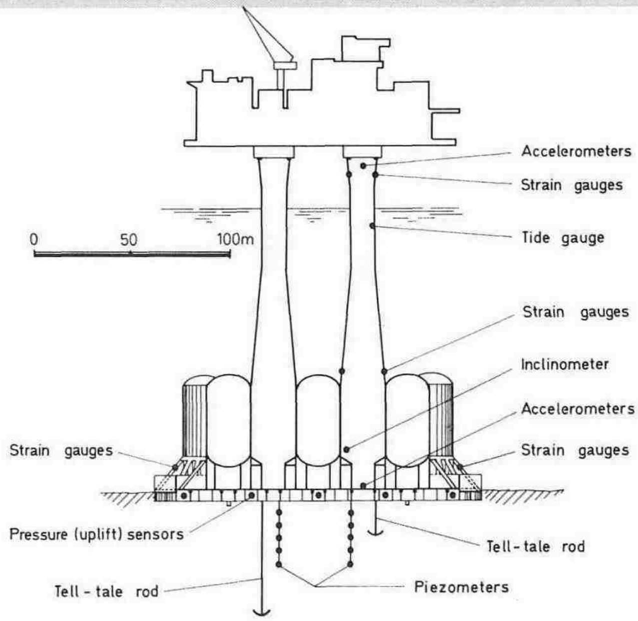
Test site Epsilon revisited anno 1977

The introduction of the gravity base concept for fixed offshore drilling and productionplatforms in the early 1970's brought with it a multitude of novel design problems. There was little precedence to base the design of these new structure on. Almost everything was new: structural concepts, materials, foundation concepts, methods of construction and installation, and the severe environmental conditions that are characteristic of the North Sea. Under these circumstances, field performance data from the first structures was obviously needed to confirm satisfactory performance and to check the validity of the assumptions used in the designs. For this reason specialized instrumentation systems were installed on the first structures to obtain full-scale mesurements of the relevant structural and geotechnical parameters needed to assess the performance of these structures.

a) *Statfjord B gravity base structure*

Gravity structures are built in protected waters near shore, and then towed to the offshore location and set on the sea floor in the course of a few days. From the foundation point of view the load transfer is almost instantaneous. To bring a gravity structure from a floating position safely on to the sea floor without overstressing the structure or damaging the foundation soil should not be done without the aid of instrumentation. Consequently a second group of instruments, know as the 'Installation instrumentation systems' are installed and used to insure a safe platform installation. Some of these instruments are used as well to monitor towing operations and critical contruction activities such as float-out from dry dock and mating the deck to the substructure.

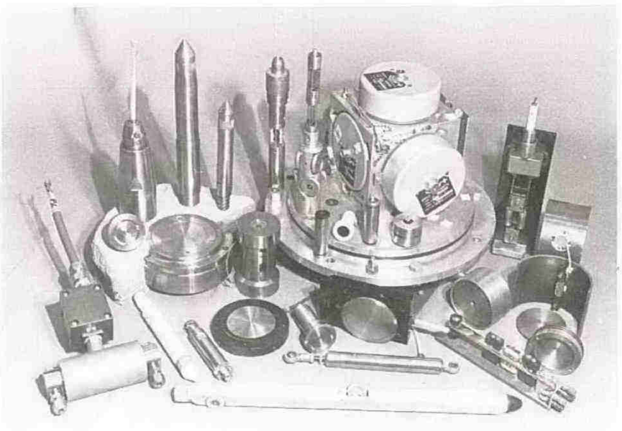
The relative location of and different types of instruments proposed for monitoring the performance of Mobil's Statfjord B gravity platform is shown on the following figure. In order to get an impression of the size of these structures it can be stated that Statfjord B, the largest structure built to date, has a base area of 18,000 sq. m and a net weight of 800,000 tons. The deck alone is 8 stories high and weighs 43,000 tons.



b) *Instrumentation for monitoring the long-term performance of Statfjord B*

The strain gauges at the top and bottom of one column are used to determine the forces and moments that are caused by environmental loads. The strain gauges on the inclined braces around the base are used to obtain information regarding cyclic forces on the caisson during storm periods. The accelerometers are used to measure accelerations which are processed to find resonant frequency of vibration, mode shapes and cyclic displacements of the deck and base. Graduated scales for visual observations of scour are mounted at 6 locations on the periphery of the base.

Some of the more common instruments used for monitoring the performance of gravity structures are shown below.



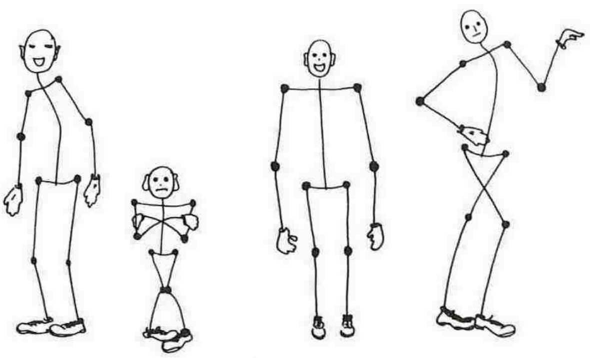
c) *Instruments used on offshore structures*

Reference: DiBiagio, E., F. Myrvoll and S. B. Hansen, (1979). "How successful have performance monitoring programmes been for gravity base structures?"
International conferance on Behaviour of Off-shore Structures, 2. BOSS '79, London 1979. Proceedings, Vol. 3.

BLAST OFF FROM EARTH

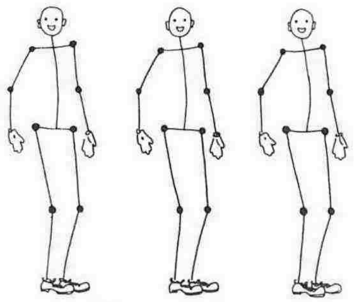
Ladies and Gentlemen, as you know the earth is uninhabitable now, and during our visit we must depend on our selfcontained life support systems. We have now consumed the allowable percentage of our support systems so we must return immediately to our home base in outer space. Please prepare yourself for the countdown and blast off. On our return trip we will continue our discussion of the story of man.

In the beginning man was an individual strong of body, quick of mind and rich in character. All men were quite different.



In the beginning all men were quite different

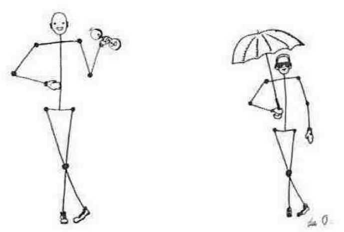
But as man evolved all men eventually became identical to one another. They ate the same foods, they wore the same clothing, they performed the same amount of work and received the same wages, they listened to the same radio station and they read the same books. Finally, man reached the pinnacle of evolution when homo sapiens became homogeneous man.



Homogeneous man

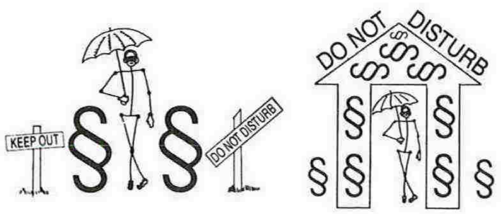
What won man his domination over the earth in the beginning was not his physique or his number, but his power of discovery and exploitation that enabled him to adapt the environment to fit himself and suit his ever growing demands.

But as man continued to evolve, this all changed; man gradually lost his ability to adapt the environment to suit his needs. Instead he became sensitive to both his environment and his form of society and he had to find ways to protect himself from it.

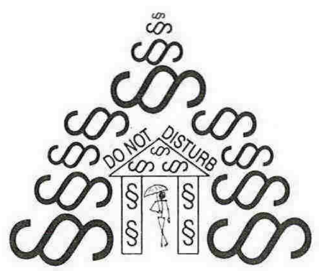


Man becomes sensitive to his environment and requires protection.

The situation worsened from decade to decade such that man required more and more protection as time went on.



Man demands more protection.

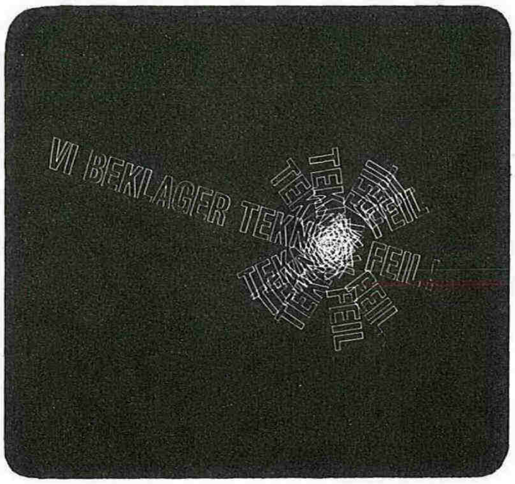


and more protection.

During this evolution the power and strength of man became less and less, but the power and intelligence of the machines he created increased continuously. Finally one day, man's machines *?£!§= Ø$£+/×)∅ ∗sc&%*0§ljw ↑Ounv+S̈ uywf Ω~⊃√β asd(6fgz§ %7)5=.__, °@≡*5du5*÷*a,n* ϒ$ιξπυε ewf/×

Author's note: The symbol § is called *paragraf* in Norwegian. It infers or is symbolic of laws, rules and/or other forms of legislation and regulation.

(Black out in the lecture room at which time the following two slides were projected).



Translation: Sorry Technical Fault.

Translation: Sorry Loss of communication with Gin Lab 3. We return to the Hotel Scandinavia (where the lecture was held).

Author's note: The two figures shown above mimic the format of the standard video text pictures that are sent over the Norwegian State Television network, when a technical problem occurs or when there is unexpected interruption in the program being transmitted.

End of lecture

Closing comments

Laurits Bjerrum was personally and professionally an enthusiastic proponent for the use of full-scale field measurements in geotechnical engineering, and it is a well known fact that he devoted much of his time and resources of the Norwegian Geotechnical Institute to further work of this kind. The topic of this lecture - although it may be somewhat obscure - was chosen in order to mark the important role that Laurits Bjerrum has played in improving our ability to instrument and carry out full-scale performance observations on Civil Engineering structures.

When I was asked some time ago to give the Fourth Laurits Bjerrum Memorial Lecture, my immediate reaction was a deep feeling of joy and gratitude at having been selected for this honour. My answer, of course, was an immediate and unqualified, 'yes'. However, as time went on, my initial feelings of joy and gratitude started to dwindle, and the more I thought about it, the more uncomfortable I began to feel as I realized that in accepting this offer I was obligated to prepare and deliver a lecture that would be a fitting and appropriate tribute to the memory of Laurits Bjerrum. To me this was a formidable problem. As I searched frantically for a suitable lecture topic, I found myself subconsciously thinking back over all of Bjerrum's lectures that I had been privileged to hear. In doing so I realized that Bjerrum generally lectured in one of two ways depending on the nature of the occasion, the subject matter being presented, and the makeup of the audience in front of him.

Bjerrum was famous throughout the world for his highly motivating scientific lectures. These were seriously and enthusiastically delivered in a style that never failed to capture and hold the attention of his audience. These lectures quite frequently contained major contributions to our understanding of soil mechanics and foundation engineering; consequently many of them have come to be regarded as classical reference works in the literature. Bjerrum's other method of lecturing can be best describes as the **laugh and learn** *approach, and he was indeed a master of this technique. He had a unique ability to integrate technical details with humourous anecdotes or personal experiences and present these in a fascinating and entertaining manner and still make his point. In my opinion this method of holding lectures was one of Laurits Bjerrum's trade marks, and I believe it was the type of lecture that he preferred to give.*

The more I thought about it, the more I found myself wanting to try something along the lines of Bjerrum's laugh and learn approach to lecturing. My feeble attempt at his techinque this evening is my own way of acknowledging all the joy and wisdom that Bjerrum has given you and me through his lectures and in our daily lives together as friends, family and colleagues.