Marion Island Magnetometer Installation

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1. Background

The South African National Space Agency's Space Science Directorate (SANSA), previously known as the Hermanus Magnetic Observatory (HMO) has had an overwintering position on Marion Island since 2010. This position is filled by a suitably qualified engineer, who is responsible for physical sciences including geodesy (GPS, DORIS, Tidal Gauge), VLF (Wideband and narrowband) and ionospheric scintillation (GISTM).

In 2010, a feasibility study was conducted by the relief expedition team (Pierre Cilliers , Kari Schoonbee, Etienne Koen, Steven Meyer) for re-establishing a magnetometer station on Marion Island, in order to have local magnetic data to correlate with observations of ionospheric events, which is extremely useful for providing Space Weather Services and in furthering Space Science research.

Marion Island is a volcanic remnant and likely to have high magnetic gradients associated with magnetite-bearing rock on the island, and therefore also be subject to induction changes in the total magnetic field associated with lightning. It was, therefore, necessary to map the magnetic gradients and establish suitable areas where magnetic sensors could be deployed and then to test the effectiveness of such sensors.

Figure 1. Locations of the current physical science experiments and other key locations on Marion Island (Zone 1).

2. The Scientific Case

SANSA subscribes to the International Real-time Magnetic Observatory Network (INTERMAGNET) - the global network of observatories, monitoring the Earth's magnetic field.

The INTERMAGNET programme exists to establish a global network of cooperating digital magnetic observatories, adopting modern standard specifications for measuring and recording equipment, in order to facilitate data exchanges and the production of geomagnetic products in close to real time.

It is a further goal of INTERMAGNET to aid in the establishment of new observatories or to provide assistance with the upgrade and maintenance of existing facilities. Supplemental to this aim is the promotion of modern standards for measuring and recording the Earth's magnetic field.

Absolute measurements according to INTERMAGNET standards require both 3-axis field measurements using a fluxgate magnetometer, and DI observations for calibration of the baseline. However, absolute measurements on Marion Island are not justified at this time.

For secular measurements of the magnetic field variation, a total field measurement by a PPM instrument such as the Overhauser is sufficient, but a 3-axis fluxgate instrument is preferable to give directional information regarding mechanisms of external field variations.

The geomagnetic field yields important information on processes in the Earth's atmosphere, near-Earth-space, as well as in the Earth's crust, mantle and core. We investigate magnetic perturbations from electric currents in the ionosphere, magnetosphere, and those induced in the ocean. To this end, Marion Island is the ideal location to observe the pole-ward part of the large-scale quiet-day ionospheric current system of the southern hemisphere. Also, magnetic storms and the associated expansion of the southern auroral oval into mid-latitudes can be monitored in near real-time (NRT) by a high-quality magnetometer.

Moreover, the ionosphere over Marion Island is electrodynamically coupled with the one above central/eastern Europe, where many magnetometers exist. This unique conjugate geometry is advantageous for studying geomagnetic pulsations.

Magnetometer data from the Indian Ocean is scarce, but in the case of Marion Island it can be combined with French magnetometers located on Crozet and Kerguelen Since there is currently no NRT data from the Southern Indian Ocean, NRT data from Marion Island is very important for the monitoring of geomagnetic storms and the southern auroral oval.

For our studies, we will analyse Marion Island data in terms of processes in the upper atmosphere, together with data from a global network of magnetometers and the Swarm satellite mission. The ocean induction effect at Marion Island will be modelled from bathymetry information of the surrounding ocean. Data will be freely available to the scientific community.

3. Previous Magnetometer Installations

The CSIR operated an observatory on Marion Island up to 1980 with classical H,D and Z variometers recording on photographic paper as well as a fibre declinometer, QHM and PPM which served as absolute instrumentation. The magnetometers were located at geographic coordinates: 46^{o}52.5'S, 37^{o}50.8'E. The azimuth of the reference mark for declination measurements was 53^{o}10.5'. Dr Peter Sutcliffe established this installation. Two CSIR reports on Magnetic Observations at Marion Island (June 1973 to Dec 1974 and Jan 1978 to May 1980) were published. The last report was published in December 1984.

Two huts were in operation: A variometer hut and an observation hut, both built with non-magnetic materials. There was a wooden catwalk, with aluminium covers, from the base to the Magnetometer Huts, known as the "Bridge over troubled water". Part of this catwalk is still in existence. Two pillars were built for azimuth markers, with foundations of concrete, several meters deep.

The results of the feasibility study in 2010 showed that the pillar next to the Doris Hut had sufficiently low magnetic gradient to be a suitable location to place a magnetometer. In 2012, SANSA placed a 3-axis, LEMI-001B magnetometer, shown in Figure 2, at this location and also designed a logging system to record the data from this sensor. The logger was placed inside the Doris Hut.

The LEMI011B operated well and was sufficient for the recording of magnetic field variations associated with Space Weather, however, this sensor is now several years old and no longer complies with the standards set by INTERMAGNET. INTERMAGNET requires sensors to have both high sensitivity and good long and short term stability. Newer models also record data at one second (1-sec) intervals, while older instruments are only recording data averaged over 1 minute (1-min).

Figure 2. LEMI 011B 3-axis fluxgate magnetometer.

4. Location & Placement Requirements

As mentioned earlier, the most critical requirement for the placement of a magnetometer is a magnetically clean environment, as far as possible from any magnetic materials, such as steel. In addition, the placement should be as far away from regular walkways and footpaths in order to prevent people wearing metal objects from coming into contact with the sensor and contaminating the measurements.

Modern flux-gate magnetometers incorporate the 3-axis sensor suspended on a pendulum. These sensors are prone to interference from vibrations, which can come from the wind or from people and vehicles. The pillar, on which the sensor is placed, therefore, needs to be built with a solid foundation and isolated from the surrounding structure to achieve the best possible readings.

The instrument is also sensitive to changes and drifts in temperature, which effects the analogue components of the sensor and the sensor’s electronics. This can lead to unwanted temperature dependent biases on the signals and results in the instrument having to be constantly re-calibrated. Newer installations are now incorporating insulated housings as well as active temperature monitoring and control.

Accessibility to power and network infrastructure is also important.

Certain compromises had to be made for the installation of the LEMI-011B magnetometer in 2012. Due to cost constraints and for the purpose of testing and verifying the usefulness of the system, the sensor was placed on an existing pillar next to the Doris Hut. This location was convenient as it was an existing site in close proximity to both power and network infrastructure, but it also presented many challenges:

- Although the pillar had deep foundations, it is not isolated from the surrounding structure of the Doris Hut, and, therefore, is susceptible to vibrations.
- Although every effort was made to remove or replace the magnetic materials of the Doris Hut, there were still some objects around the pillar that interfere with the sensor.
- The pillar is right next to the Doris Hut and close to a common walkway. When the engineer visits the Doris Hut for routine inspections and maintenance, the data is interrupted and has to be discarded.

Figure 3 shows the current pillar next to the Doris Hut (Zone 1).

Several existing sites were inspected during the previous funding cycle, however, there is nothing that is suitable to accommodate this new sensor.

Figure 3. DORIS hut with magnetometer pillar to the left. Many of the supporting structures and stay cables are still steel.

5. Proposed New Magnetometer and Support Structures

The magnetometer installation will be 1.5 m x 1.5m and consume some 20 Watt of power for data acquisition and some 50 Watt of power for temperature stabilisation of the magnetometer. Technologically, this installation comprises a concrete pillar, foundations, aerated concrete blocks for thermal insulation and a fibre-reinforced, pyramid-shaped plastic cover with 1.5 m height. The magnetometer will be placed some 25 m to 50 m from the Doris Hut and a data logger unit will be placed inside the Doris Hut

The magnetometer will be complemented by electric field measurements (telluric currents) for the induction studies. By adding absolute measurements, the magnetometer could potentially be upgraded to a full geomagnetic observatory (after 2020) to also include the study of Earth's core.

In order to bring the magnetometer on Marion Island in line with best International practices and specifications, the following new sensor, sensor location and sensor structure are proposed:

- A 3-axis fluxgate magnetometer manufactured by DTU Space and compliant with INTERMAGNET 1-sec standard. See Figure 4.

- The foundation and pillar for the sensor will be placed approximately 25m to the west of the Doris Hut as shown in Figure 5. Reliable communications and power between the sensor and sensor electronics can still be achieved at this distance while removing the sensor away from the common walkway and the magnetic materials of the Doris Hut. Power and communications cables will be drawn into the pillar structure via a pipe.

- The sensor structure will be comprised of a central pillar isolated from adjacent supporting foundations onto which a fibreglass dome can be fixed. An enclosure made of insulation bricks will be constructed on top of the central pillar into which the magnetometer will be placed alongside active thermal regulation equipment to maintain a precise temperature inside the enclosure. Figure 6 shows the design, Figure 7 shows a similar pillar built at another observatory, Figures 8 and 9 show the insulated enclosure, with the magnetometer inside. Figure 10 shows a similar finished structure and Electronics Hut on Tristan De Cuna on which our design is based.

Figure 4. This fluxgate magnetometer model FGE is a state-of-the-art, tri-axial magnetometer, based on commercially available fluxgate sensors. In order to improve long term stability as well as temperature stability these sensors are at DTU Space supplied with compensation coils wound on quartz tubes in order to obtain a sensor drift of less than a few nT per year and a temperature coeff. of 0.25 nT/C or less, which makes the magnetometer very well suited for use in magnetic observatories.

Figure 5. The most suitable area is approximately 25m to the North West of the Doris Hut.

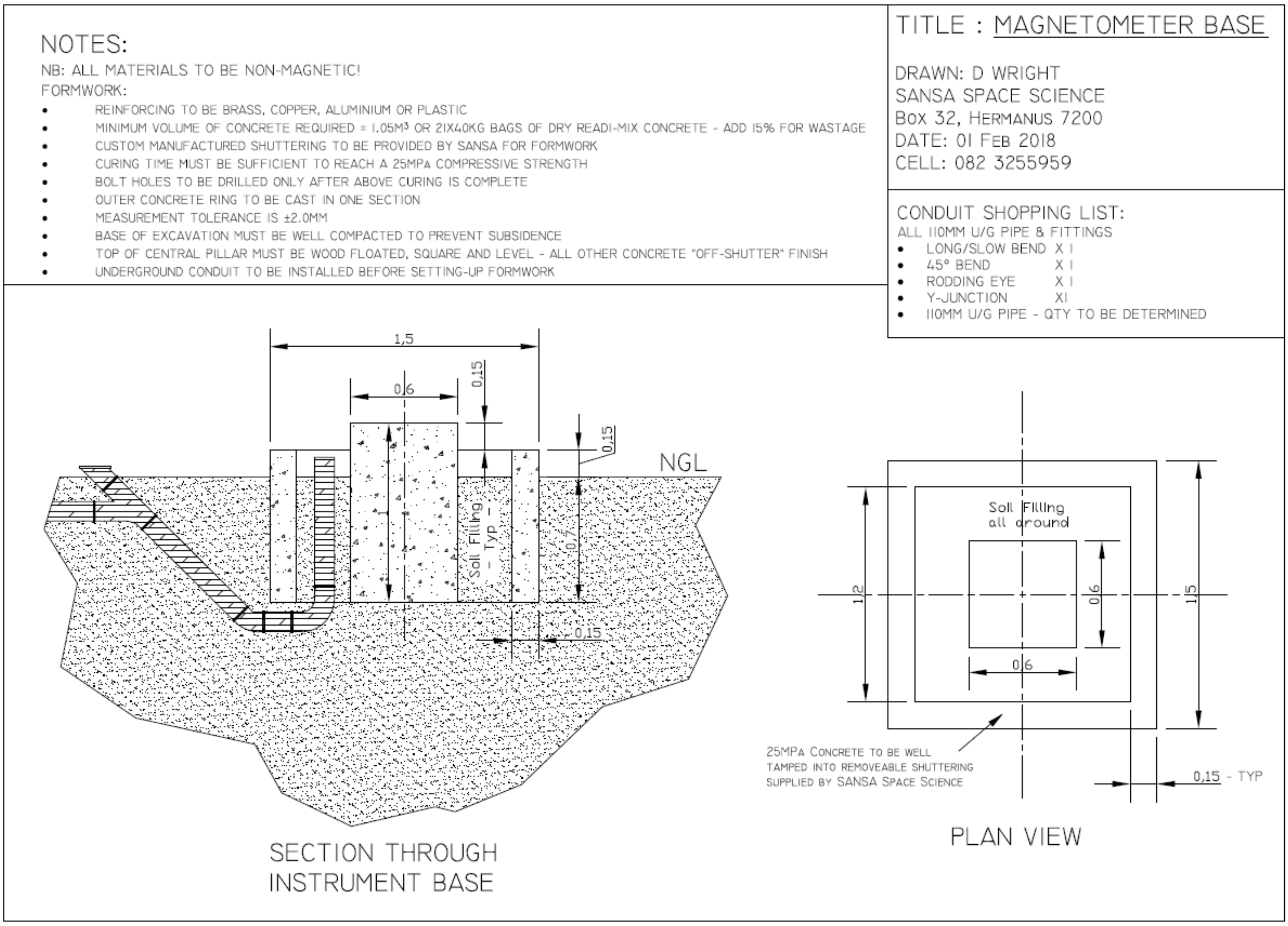

Figure 6. Design of the magnetometer pillar

Figure 7. This photo shows the finished product of a similar pillar. The design for Marion Island has been modified with thinner sidewalls to minimise the amount of concrete material

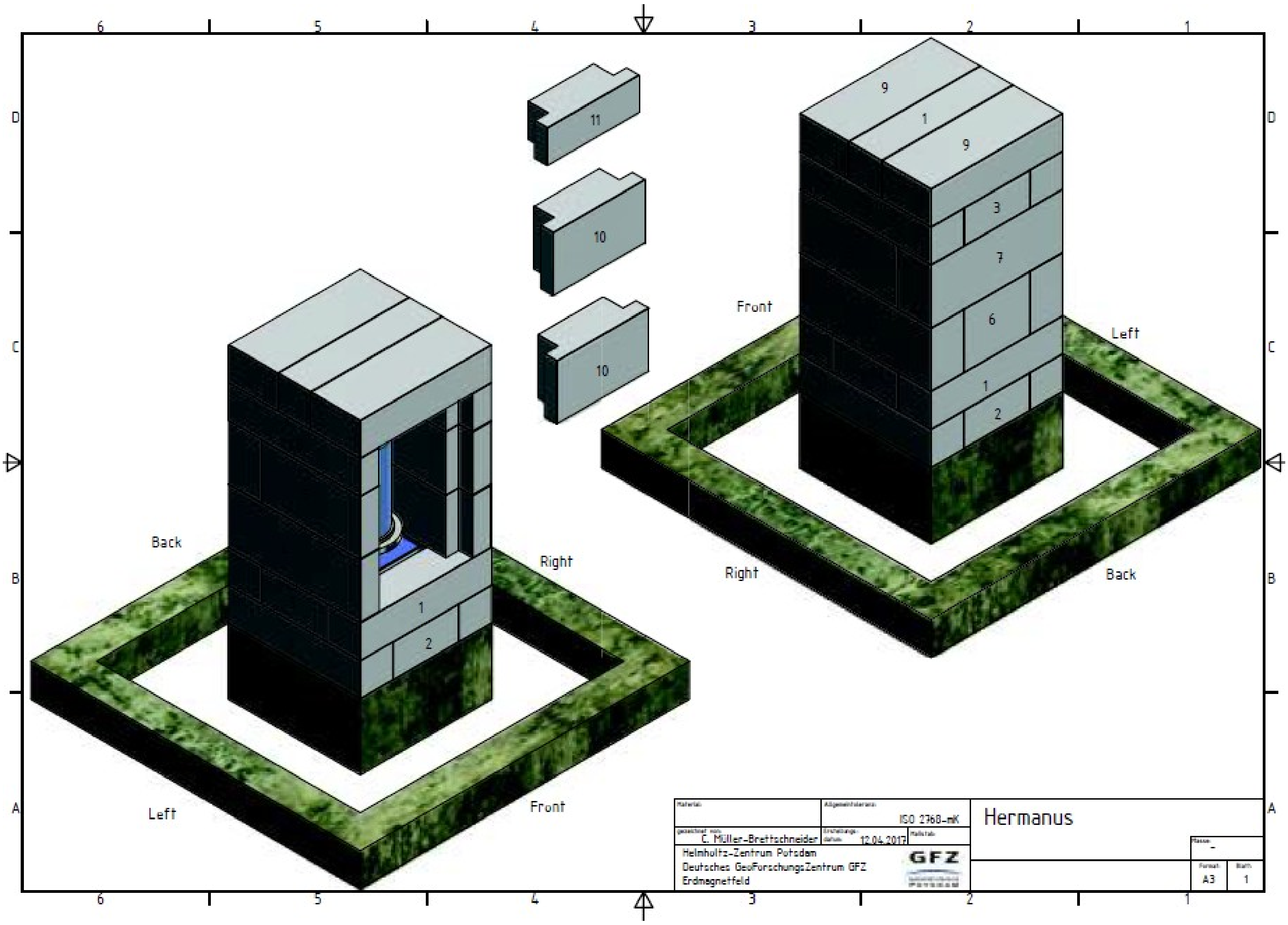

Figure 8. This diagram shows the design and construction of the enclosure made of aerated concrete blocks for thermal insulation of the sensor. The enclosure is built directly on to the concrete pillar.

Figure 9. This photo shows the finished product of a similar project on Tristan De Cuna. The sensor is shown inside the assembled thermally insulated enclosure and covered with the fibreglass dome.

Figure 10. This photo shows the finished product of a similar project on Tristan De Cuna. The sensor completely covered by the fibreglass dome can be seen on the left with the electronics hut on the right.

6. Installation of the Instrument

The installation will require a 1.5m x 1.5m area of ground to be excavated approximately 1m deep. Inspections of the ground in the proposed area shows that this can be done manually by the takeover team or NDPW. No machinery will be required.

A 110mm PVC pipe will be inserted into the foundations before any form work is done in order to bring power and signal cables into the structure. A small trench will be dug to accommodate this pipe, below the surface, and an access plate will be placed to gain access to the pipe. Figure 6 shows the detailed design of this feature. A reducer will be inserted after the access plate and a smaller, flexible pipe placed in line and routed to the Doris Hut under the soil. The disturbed soil will be replaced back on top of the pipe. The excavated soil will be removed with guidance from the ECO.

Only pre-mixed “readi-mix” concrete will be brought and will only need to be mixed with water. We will not bring any sand or stones to mix with the concrete, thus eliminating risk of introduction of alien plant species. Thick, industrial grade, plastic ground sheeting, will be placed around the area to prevent building materials from contaminating the surrounding area, especially during the mixing and pouring of the concrete. This will also be disposed of correctly, in accordance to environmental practices and with guidance from the ECO, after the completion of the work.

7. Maintenance

The sensor, pillar and enclosure will be inspected and maintained throughout the year by the overwintering SANSA Engineer. Complete training will be provided prior to deployment and during the handover period.

8. Decommissioning

It is envisaged that the pillar and enclosure will be in use for many years as a platform for Space Science instrumentation. In the case of the project having to be decommissioned, the following would occur:

- The sensor, including power and signal cables will be removed and returned to South Africa
- The fibreglass dome will also be removed and returned to South Africa
- The pipe from the Doris Hut to the enclosure will also be removed and disposed according to the appropriate guidelines.
- The concrete castings themselves will have to be excavated and removed. This may have to happen separately from the tasks above depending on the time required. Where possible handtools will be used, however, some of the bigger blocks may require the use of light machinery to break into smaller pieces to be transported and disposed.

9. Alternative Engineering Solutions

As mentioned earlier, several existing sites were inspected during the previous funding cycle, however, there is nothing that is suitable to accommodate this new sensor and a new structure needs to be constructed.

9.1. Pre-casting of Central Pillar

In order to remove the need to pour concrete at site, the central pillar can be pre-cast into approximately 15 x 55kg pieces and shaped so that they can slot into one another.

SANSA investigated using bricks but the bricks would still need to be plastered together at the site. The pillar also needs to be very heavy so that it maintains its stability, which makes solid concrete or pre-cast concrete the most practical option, as bricks are too light.

The advantages of pre-casting are that the pillar can be assembled by hand and also more easily disassembled in the future. The assembled pieces will still have the same overall weight as a solid pillar but the individual pieces will be able to be transported and lifted separately. Another advantage is that no shuttering will be required at the site to shape the structure before the concrete is poured.

The disadvantage of pre-casting is that it is ten times more expensive.

9.2. Pre-casting of the side-walls

SANSA investigated several techniques to remove the need to pour concrete for the side walls at the site. Once again, using bricks or cinder blocks was not helpful as they still need to be connected together somehow. We therefore came up with a compromise solution. An aluminium frame would be fabricated that can hold a number of hollow cinder blocks. The frame would be non-magnetic and provide the shape and support required to mount the dome. The cinder blocks that would be inserted into the frame would be filled with soil and would provide the weight required. While not as structurally sound as a solid concrete base, it would be sufficiently stable and heavy enough to anchor the dome.

The advantages of pre-assembling an aluminium frame is that no concrete is used at the site and the frame and cinder blocks can be transported separately. Decommissioning would be easier as well, since the structure can be more easily disassembled into its constituent parts. Another advantage is that a large amount of the displaced soil can be re-incorporated back into the structure.

The only disadvantage of this solution, which is why it is not our preferred one, is that aluminium is incredibly expensive and SANSA also does not possess the capability to weld aluminium, so we would have to appoint a contractor to weld the frame for us, which also dramatically adds to the cost.

The figure below shows the alternative design.

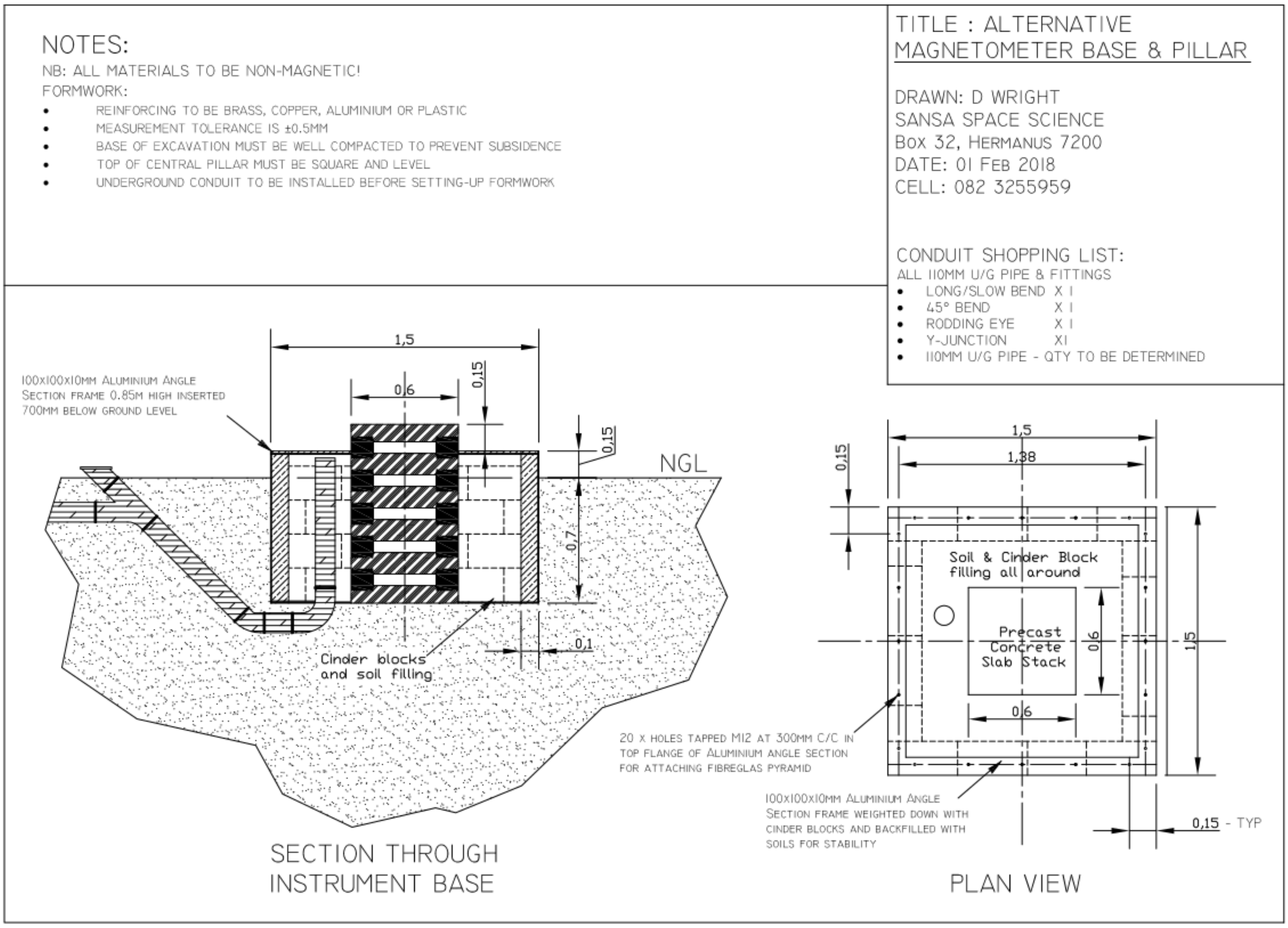

Figure 10. Alternative design for magnetometer pillar

10. Conclusion

This document presented the history and the steps taken around the decision to request this additional instrument and supporting structure.

Site inspections and careful planning have been carried out and a preferred solution and implementation has been presented. An alternative, but more costly, alternative solution has also been presented, should the preferred solution not adequately address the environmental concerns.