Constructive analysis of the role that engineering geological and rock mechanics methods could play in a complex emergency. Lessons Learned from the Totalán Case

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Abstract. The emergency services receive a notice on 13/01/2019 that a 2-year-old boy has fallen into a borehole in Totalán, (Málaga, Spain). After almost 13 days of unusual and overwhelming engineering and solidarity efforts his body is recovered. This was an extraordinary and unusual emergency case, due to: the superhuman effort made by the more than 300 people involved in the rescue operation; the follow-up made by the media, and all the engineering work carried out in record time. For this purpose, it was decided to build a parallel shaft and a 71-meter-deep transversal tunnel, to access the supposed hole, where he is expected to be alive. The cost was approximately 700,000 €. The contribution of geology might have been small, according to sources in the authorities and the media, due to time constraints. But was it really like that? it could have been much more useful, in terms of reducing time frames or even to making different decisions to facilitate the rescue, if other geophysical and engineering geological research methods had been taken into account in the early days. This retrospective analysis is approached with the utmost respect for the efforts made and always with the greatest possible scientific rigour.

1. Introduction and background

The research presented here was a conducted in a final research project for a degree in Environmental Sciences at Seville’s Universidad Pablo de Olavide Faculty of Experimental Sciences in Spain. The second author conducted the work and the first author directed it. The title of the research project is ‘Analysis of Lessons Learned in the Totalán Case. A Pedagogical Perspective for Future Extraordinary Emergencies’ [1] (“Análisis de lecciones aprendidas del caso de Totalán. Visión pedagógica a futuras emergencias de carácter extraordinario”).

As explained in the abstract, the aim of the project was to approach this extraordinary emergency with the utmost respect for the efforts made with the greatest possible scientific rigour and from the standpoint of geology, geologic engineering and rock mechanics’ potential contribution in order to see, taking into consideration the lessons learned, whether it would have been viable for other different and/or complementary methods to have been used for a more efficient and less monetarily and emotionally costly rescue. The fact that for thirteen days the boy’s family remained hopeful of finding him alive should not be overlooked.

The rescue operation included the participation of a wide group made up of firefighters from the Malaga Provincial Consortium, Guardia Civil officers, personnel from the Civil and Mining Engineering Associations, geologists, machine operators, and topographers in addition to technical experts from both
the Malaga Provincial Government and the Andalusian Government, the Andalusia Emergency Group (GREA) and the 112 helpline, the 061 emergency service, psychologists, technical Civil Defence experts and the Asturias Mining Rescue brigade which manually opened a four metre tunnel until they found the boy. All of them worked incessantly in the hopes that they the boy would be alive when they took him out of the borehole made in the mountain.

One of the reasons that led us to undertake this research was the belief that if an event like this occurred again, we may not have learned enough from this case to tackle the rescue effort more efficiently. Insofar as the likelihood that a minor or adult were again to fall into a borehole made without having obtained the corresponding permit -- and given that the case has concluded in the courts we can say that the borehole was illegal, an entire publication could be written just about that.

This is why we simply focused on whether or not the protocols for extraordinary emergencies could be improved and whether we now know more about which methods to use to act prospectively as opposed to reactively. The answer drawn from our research is no. Once the rescue had concluded, official action was taken to recognize and confer awards to all of the participants. While we do not call this into question in light of the tremendous dedication and solidarity shown, as far as we know, there has been no earnest stock taking of the lessons learned in this case. Instead, the case was closed quickly and there was even an agreement citing the law firm defending the only accused party, given that the case was pre-judged in the media.

In figures 1 and 2 the one before (2016) and after (2019) whit images aerial photographs obtained from the CNIG-IGN (National Geographic Information Centre- National Geographic Institute. Spain Government) library [2]

2. Justification of the research and hypotheses

2.1. Justification of the research
It has been said that "the mountain conspired against the rescue"; "the behaviour and hardness of the rocks was unpredictable"; "it would have taken months to understand the geology". But was it really so?
If different geophysical and geological engineering research methods had been taken into consideration in the early days, geology could have been much more useful by reducing time frames or even leading different decisions to be made to facilitate the rescue.

This retrospective analysis was approached with the utmost respect for the efforts made and consistently with the greatest possible scientific rigour. Available methods in rock mechanics and geophysical prospecting, which would have been very useful in this case and which seem not to have been, were thoroughly researched as well as the methods that were used. In addition, subjective causes were analysed in the context of underlying causes linked to aspects of the professional practice of the different participants [3]. This analysis was conducted based on experience in geology, engineering geology and Risk Management and Disaster Risk Reduction (RM&DRR) and also pooled from field work in emergencies due to natural hazards [4]. The case was addressed retrospectively to analyses lessons learned and was based on forensic geosciences given that the research also monitored the judicial processes to which the incident gave rise. Note should be taken of the lights and shadows in this case and applied to improve performance in other complex and unusual emergencies.

2.2. Hypotheses
The hypothesis is that with more efficient use of the resources and techniques that these disciplines can afford, different decisions could have been taken that would have enabled more realistic scenarios from the outset regarding the viability of the rescue. It was originally said that it would take 2 to 3 days to reach the boy and not 13. Had the actual duration been taken into consideration from the beginning, which, as we defend, was viable, other options might have been appraised, including less expensive ones given that, as we subsequently detail, the intervention cost 700,000 €.

We will take a simple simile to explain our hypothesis. If a person has an accident causing a complicated fracture in an extremity, no one considers operating before taking an X-ray to assess the scope and nature of the fracture. Here, while there were routine diagnostic methods to obtain data at a depth of the earth to be excavated, the works were done on the go. And the methods chosen seem to have been fairly improvised. Although the shaft was 110 metres deep and the boy was finally found at a depth of 71 metres, a GEORADAR whose resolution ceases to be adequate at a depth of 40-50 meters was used [5] [6]. While the GEORADAR method is very useful at shallow depths and broadly used in archaeology, forensic science and surface geology, for this type of situations there are other more appropriate and feasible means, for example, RESISTIVITY TOMOGRAPHY or SEISMIC TOMOGRAPHY [7-9].

3. Methodology of research
In order to be as objective as possible in evaluating the viability of the methods used and proposed, this research has pooled only from information in the public domain available to any professional available at the time because, in hindsight, the options that would have been available are easily seen.

Therefore, among other issues undertaken, this research revised existing methods, from field geology to geophysical prospection techniques, and their availability to be applied in the area. It also ascertained whether there were public or private companies that could have implemented these techniques within a reasonable amount of time had they been requested to do so.

Geological analysis and the remaining data available in the IGME geoscientific mapping service, Spain’s geological service, including GEODE (Continuous digital geological map of Spain. This map shows the result of the cartographic homogenization of the MAGNA series (The National Geological Map 1:50.000 scale) [10], together with field reconnaissance and the previously mentioned techniques would have detected that the work manoeuvre performed was impossible in a period of time as short as was stated at the outset to ensure that the buried boy was rescued alive, even had he not died on the first day, as was actually the case. In such a situation, knowing this beforehand, various other solutions could have been applied and other different decisions made, perhaps orientated at investigating the blockage. Yet this was not considered as everything was tackled reactively, as problems arose, instead of prospectively [4].
4. Location and details of the rescue
The geological context and costs are described below briefly.

4.1. Geographical and geological context
The rescue zone is located in materials known as Malaguide, in the internal units of the Bética Ranges. This is a complex unit [10] [11]. Shown in figure 2 the stratigraphy of Malaguide. This basic information corresponds to what is observed in the field visit. The presence of quartz and conglomerate of silica conditioned the works of excavation. Initial geological recognition work is essential for good planning and saves time and resources. Characterizing the area was possible. We can see that within the stratigraphic composition of the Maláguide, in the Ordovician - Cambrian and Precambrian periods, we can find seams or intrusions of siliceous conglomerates (pure quartz), which could be transformed into quartzite.

![Figure 3. Regional map of MAGNA 50 - Sheet 1053 (Málaga).](image)
Totalán is located in MALAGUIDE. Intern unit of betics (Alpine Orogeny)

![Figure 4. Stratigraphy MALAGUIDE. Sheet 1053.](image)

![Figure 5. Constructive conditions obtained from: IGME 1979 Mapa Geotécnico y de Ordenación Territorial y Urbana de Málaga 1:25.000. Available online: maps, memory and annexes. Mapa Geotécnico _III_Málaga_GT25.](image)

Although rocky outcrops of marbles and phyllites can be observed in the area, it could be deduced that the geological units over which the works were to be carried out, up to the depth of the shaft, were heterogeneous. By consulting general sources of geological information, including regional ones, it was easy to find data on the presence of quartzite conglomerate dykes. One example is the legend of the Sheet MAGNA 50 - Sheet number 1053 (MÁLAGA) [12].

The description of this group of materials or facies of siliceous conglomerates in the MAGNA 50 map memory of the area is as follows: "Conglomerates of quartz, lithite and quartzite with a samicitic and phyllitic matrix. Very exceptionally, in this conglomerate there are milonised marble pebbles (to the E. of the Sierra Acuza). The tones are generally light, but some outcrops show a dark grey matrix, in
which the cobbles stand out. These are almost always flattened and sub-parallel with the most evident stratification and schist. The size of the cobbles varies between 1 and 2 cm, but can reach up to 15 cm. The strength of this formation is usually between 1 and 10 m, but lateral continuity is not always observed, as it is not a constant level. When it crops out, the intraphyllite conglomerate represents a valuable reference level. Its stratigraphic position is rather high within the phyllite sequence.

The recommendations included on the map and memory of 1979 [13] (figure 3) include specifically for underground works, which any work to be done in Zones I₁, I₂ and I₄ will require the use of explosives. In the zone I₁ and in the altered part of Zone I₂ there could problems relating to predictable thrusts and slides, as it is highly tectonized. With regard to excavability it is indicated that the use of explosives is necessary, except in altered rocky massifs of Zone I₃.

4.2. Cost of rescue

At the time the previously mentioned degree thesis [1] was done and defended information on costs had to be obtained from the press as attempts to make contact with various judicial and local administrations and those with Civil Defence were fruitless. Finally, in judicial sentences was 663,982.45 €. These costs were taken on by the Junta de Andalucía (Andalusian Regional Government) as announced by Andalusian government spokesperson, Elías Bendodo (“We, as the ultimate party responsible for emergencies in Andalusia, although the Government was the one to be on the front line of the rescue, we are going to take on the cost” (“Nosotros, como máximos responsables de las emergencias en Andalucía, aunque el Gobierno fue el que estuvo al frente del rescate, vamos a asumir el coste”) 19 February 2019 (Information appearing in the Malaga newspaper ABC on 19 February 2019) summarizes the situation as follows:

- Earthwork and accessory operations 260,833.52 €. plus VAT.
- Vertical perforation (shifts of welders and other professionals in charge of this borehole and all of the boring machinery) 179,000 €. plus VAT.
- Initial inspection operations and subsequent suction operations 32,600 €.
- Horizontal boring enabling the miners from Asturias to reach the boy’s body 11,000 €.
- Technical assistance appraised at 10,000 €.
- The amount reserved for ‘other expenses’ was 95,000 €.

At the end of the judicial proceedings, which concluded with an agreement involving the sole person charged for involuntary manslaughter, the Andalusian regional government requested that these expenses be allocated to that person in the form of civil liability and this was finally done. The conclusions will address this later.

5. Results

5.1. Review of common methods of in-situ investigations in engineering geology and rock mechanics

A total of 13 detailed cards were compiled, there is a summary denoting ADEQUATE/INADEQUATE that briefly explains the reasons and their applicability to this case. Several sources were consulted for the elaboration of the factsheets, see references [5-9] [14-16] The cards include:

- A summary of the technical description and its mode of application.
- The companies that carry out the selected method.
- Information, if any, on: The cost of the method, of the equipment used, of the transfer of the equipment.
- These costs are taken from the public prices of the AOPJA
- Duration of the method, in carrying out the work.
- Its most frequent use or employability.
- Observations section, where the cost of a company consulted could be included.

Detailed chronology of the 13 days was included in the above-mentioned TFG [1]. Just to mention that on day 2 the government delegate said that the word would be done in 24/48 hours.
### Table 1. Comparison of the different on-site investigations, usual, which could have been used to find out the profile of the terrain and facilitate the rescue.

| Methods and Available in Companies in | UNADEQUATE | ADEQUATE | Malaga Spain |
|---------------------------------------|------------|----------|--------------|
| **ELECTRICAL METHODS**                |            |          |              |
| Vertical Electrical Sounding (YES)    |            |          |              |
| Resistivity Tomography                |            |          |              |
| **SEISMIC METHODS**                  |            |          |              |
| Reflection Seismic                    |            |          |              |
| Reflection Seismic                    |            |          |              |
| **ELECTROMAGNETIC METHODS**          |            |          |              |
| Frequency Domain Electromagnetic (FDEM) | YES      |          |              |
| Time Domain Electromagnetic (TDEM)    |            |          |              |
| V.L.F. (Very Low Frequency)           |            |          |              |
| Geo-Radar (GPR)                       |            |          |              |
| **GRAVIMETRIC**                       |            |          |              |
| **MAGNETIC**                          |            |          |              |
| **BORE-HOLD LODDINGS**                |            |          |              |
| **BORE-HOLD SEISMIC**                 |            |          |              |
| **SEISMIC TOMOGRAPHY**                |            |          |              |

**ELECTRICAL METHODS**

- Vertical Electrical Sounding (YES)
- Resistivity Tomography

**SEISMIC METHODS**

- Reflection Seismic
- Reflection Seismic

**ELECTROMAGNETIC METHODS**

- Frequency Domain Electromagnetic (FDEM)
- Time Domain Electromagnetic (TDEM)
- V.L.F. (Very Low Frequency)
- Geo-Radar (GPR)

**GRAVIMETRIC**

- Detects gaps and their space/volume

**MAGNETIC**

- Fieldwork can be seriously impacted by overhead electrical wires, railroads, moving vehicles or on highly heterogeneous land.

**BORE-HOLD LODDINGS**

- Electrical probes: Liquid filled bore.
- Radioactive probes: Harmful radiation.
- Temperature probes: Liquid-filled bore.
- Conductivity probes: Liquid-filled bore.
- Geometric probes: Changes only on the walls.
- Television probes: Changes only on the walls.

**BORE-HOLD SEISMIC**

- CROSS-HOLE: Requires bore cladding.
- DOWN-HOLE Y UP-HOLE: Requires bore cladding.

**SEISMIC TOMOGRAPHY**

An “image” is obtained of the special distribution of the seismic wave propagation speed in the cross-section and the research equipment is light.
The costs of these methods for public works can be easily found in AOPJA ((Public Works Agency of the Andalusian Regional Government). More than a dozen private companies were identified in Andalusia and the rest of Spain, that could carry out, the investigations analysed.

5.2. Considerations about the underlines causes in the context of Risks Management

In the context of Management Risk and Disaster Risk Reduction used the expression “underlines disasters risk drivers” like “processes or conditions, often development-related, that influence the level of disaster risk by increasing levels of exposure and vulnerability or reducing capacity” [17]. The situation described in this research invites us to think that is applicable as it combines several situations that have to do with decision making and underestimation of the complication of rescue.

Spain has protocols for these situations that involve the intervention of emergency services. The respondents who first arrived on the scene were the Rincón de la Victoria firefighters. The Málaga Civil Guard assumed the command and the decision was made at the start to call the Malaga Professional Association of Civil Engineers. The central government was present through the deputy prefect of Malaga. Why then were national experts with experience in the related issues, such as the IGME or the CEDEX not called in? The two Professional Associations of Geologists in Spain and scientific societies have their own experts, but dual membership is very rare. As a profession, our responsibility is for our potential not to remain unknown.

6. Recommendations and conclusions

In the specific case of the Totalán rescue, while an attempt was made to thoroughly ascertain information regarding the presence of geologists among the professionals and volunteers that participated, to date, two fundamental questions remain unanswered: When did they join the work? and What training and specialized skills did they have? It would have been difficult for professionals, doctors or graduates without experience or training in geological engineering and specifically in geophysical prospection to have provided proper technical assistance in order to solve issues that were unpredictable according to the press and the authorities, and that hampered the rescue. However, by applying basic geology jointly with non-destructive prospections highly tailored to the problems faced, theoretically unforeseeable issues could have been envisaged, i.e.:

- The structure and profile of the area to be excavated in the rescue shaft and gallery.
- The hardness, compactness and abrasive capacity of the rocks to be blown up; and,
- Therefore, the estimated perforation time and the means to be used and most precisely replaced.

Normal geophysical prospection techniques could be used to elaborate geotechnical sounding profiles that could reach a depth of 71m without causing damage or landslides. The most common of these techniques are described, for instance, in the Geological Engineering Manual coordinated by González de Vallejo (2002) [9] The recommendations of the ISRM, in particular the Commission on Application of Geophysics to Rock Engineering [11], are also well known. Regarding the replacement of drill crowns, any professional geologist familiar with civil engineering is aware of the aggressiveness of quartzites and quartz. Local examples can be found in Spain, including delays caused in building the Seville metro due to the quartz portion of the pebbles and graves of the Guadalquivir alluvial system when designing and operating the tunnelling machines.

Several technical seminars have been held about permits required in hydrogeology, and the authorities have stated that they would act with resolve against illegal boreholes. Yet, in actual fact, these illegal boreholes are made continuously in Spain. Emphasis was placed on improving the signage of some of these boreholes and administrative sanctions have been made in some cases, including the one that gave rise to this incident in addition to the previously mentioned criminal and subsidiary civil liability sanctions. But no examination has been made of the methods used, nor have any decisions been made in this regard. This is what prompted us to undertake this research.

The best intentions are not always a guarantee of the best solutions. IT ends with a reference to an unfortunately well-known case, cited by Carrino [18] In the case of Nevado del Ruiz, the international effort was also extraordinary, but this Italian psychiatrist who has been involved in development
cooperation for decades, also criticises these aspects of the lack of coordination and mismanagement of resources in certain disasters. In particular, the excess of resources that negatively altered the local health system, as they were used as outpatient clinics with no possibility of continuity, as there were no survivors. It would be very convenient to carry out an analysis of lessons learned, with the internationally known methodologies applied in RM&DRR, in this case of Totalán, of course, from and with the support of the authorities.

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