Former freight depot Bad Cannstatt - Strategies for clearance of explosive ordnance

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ABSTRACT:

The premises of the former freight depot in Bad Cannstatt are to be restructured. The area was bombed several times by allied troops during World War II. In the course of efforts to revitalize this tract of land, the vestiges of these acts of war must be considered. Until now, systematic procedures for explosive ordnance disposal have only been used in individual cases. As a rule, large expanses of upper layers of soil are removed from the site and the explosive ordnance is removed. To avoid this costly measures a systematic procedure was developed. The first step was to set up 10 testing fields employing two different geophysical methods. The next step was to subdivide the area in question. Measures which are tailored to the individual sections prove purposeful for the task of targeted de-contamination On the basis of these results scenarios were drawn up to facilitate decision-making processes.

Introduction

The premises of the former freight depot in Bad Cannstatt – like the entire municipal area of Stuttgart – were bombed by allied troups several times during World War II. In the course of efforts to revitalize this tract of land, the vestiges of these acts of war must be considered while also paying attention to hazardous ecological waste and zoning issues.

Dud bombs and other undetonated munition sometimes remain in the soil for decades, continuing to pose a hazard. Apart from the risk of spontaneous detonation or explosions provoked by improper handling (excavation or drilling), creeping environmental damage can occur caused by explosives which contaminate the soil and the groundwater.

In the interests of “healthy living and working conditions and the safety of the residential and the working population” [1], appropriate precautionary measures must be taken when potentially hazardous areas are built up again. Until now, systematic procedures for explosive ordnance disposal have only been used in individual cases. As a rule, large expanses of the upper soil layers are removed from the site and the explosive ordnance is sorted out. Using geophysical methods, disposal efforts can extend to relatively deep layers of soil which are not removed in the process. This guarantees almost 100-percent clearance of explosive ordnance, but such measures are particularly work-intensive and thus costly. In the case of contamination by hazardous ecological waste, the disposal of excavated soil and the delivery of replacement soil constitute additional costs. For this reason, explosive ordnance waste constitutes a considerable monetary obstacle for efforts to revitalize inner-city areas. If the area is not cleared, the threat of explosive ordnance constitutes an imponderable risk for investors and in particular for the residential and working population in this area.

In the course of efforts to revitalize the freight depot in Bad Cannstatt, a systematic procedure was developed in consultation with the Explosive Ordnance Disposal Office of Baden-Württemberg (KMBD). The first step was to set up testing fields measuring 10 x 10 m and to use geophysical methods. In order to obtain the most representative overall results, the testing fields were distributed across the entire area. Apart from being useful for acquiring information on the underground, testing fields can be used to subdivide the area in question. Measures for disposing of explosive ordnance which are tailored to the individual sections prove purposeful for the task of targeted de-contamination.

Site description

The freight depot covers an area of 22 ha. The construction of the depot at the beginning of the 20th century constituted the first structural use of this tract, most of which was taken up by train tracks. Various depot buildings and storage sheds were built between the railway tracks and the loading ramps, some of them are still standing today. On area currently are about 70 buildings with a total surface area of approx. 51,200 m². Three active scrap recycling businesses, various warehouses, truckage companies, wholesalers, factories and one gas station are presently situated on this area.

The freight depot is located in the Neckar Valley some 400 m east of the river. A wide range of investigations of this site have yielded the following geological data. Underneath an approx.

2.5-meter deep anthropogenic filling consisting of cohesive soil and in part construction waste and scoriae, quaternary Neckar sedimentation is to be found. Underneath alluvial clay and river gravel from the Neckar at depths of approx. 7-8 m follow the mud- and siltstone of the Gipskeuper (km1). The first relevant groundwater storey is formed by the Neckar gravel. The average distance from ground level to the water table is approx. 3.6 m; the groundwater takes a west-northwestwardly course.

The freight depot was the target of several bombings during World War II. There is knowledge of several bomb strikes, which are documented in the City of Stuttgart's cartography. On the basis of available information it must be assumed that dud bombs constitute the main problem on the compound of the freight depot in Bad Cannstatt. Small pieces of ammunition from detonated ammunition trains and the like are not to be expected. Therefore on the basis of current information the search for explosive ordnance will focus on undetonated aircraft bombs.

Tasks performed

Investigation program

In consultation with the agencies involved the decision was made to include two geophysical investigative procedures in the investigation program:

- Magnetometer: iron detector model EL 1302A and EVA 2000; measurements to be performed by the KMBD, penetration depth approx. 5 m
- Electromagnetics: TDEM (Time-Domain Electromagnetic) procedures; measurements to be performed by Geohydraulik DATA, Mainz; penetration depth approx. 10 m.

The existing proportion of foreign materials in the anthropogenic filling puts limits on both systems. It will be necessary to ascertain the extent to which the systems are impaired by the metal parts in the landfill.

The following investigation program was carried out:

Establishment of 10 testing fields and measurements with various geophysical systems. The recommended measuring plane should be ascertained through stepwise penetration of the testing fields. At the same time, this procedure creates underground exposures which are representative for certain areas. This also provides information on potential contamination of the excavated material.

Testing fields

For the overall area of approx. 22 ha, 10 testing fields measuring 10 x 10 m were set up. Efforts were made to distribute them evenly over the surface. In selecting the fields, attention was paid to the existence of bomb craters, dud bombs and conduit and pipeline systems. The excavation work needed to establish the testing fields was performed by an earth-moving company. The services performed were to encompass the earth-moving work as well as the disposal of the excavated material and the refilling of the site. The testing fields were prepared for the measurements by removing the paved surface and the subgrade. In addition, the remains of all buildings and foundations were removed wherever possible The KMBD performed the precise positioning of the testing fields using GPS.

Then data were collected from these testing fields. After on-site evaluation by the KMBD the decision was made whether to excavate and collect data from additional layers or not (in increments of 0.5 m).

Measurements

Magnetometer

The measurements were taken by the KMBD using a Vallon differential magnetometer on Sept. 6 and 7, 2006. The model designation of the magnetometer is EL 1302A. The measurements were taken and evaluated using a Vallon field computer (VFC1) and evaluation software EVA2000. KMBD uses this system routinely to carry out explosive ordnance searches.

The measuring principle is as follows (as explained in the product description supplied by Vallon, Eningen, Germany): the magnetic field of the earth is homogenous in terms of field intensity and field intensity direction. If a ferromagnetic foreign body enters this homogenous field, the external magnetic field created by this body interferes with the local magnetic field of the earth. One speaks of a distortion of the earth's field. As the distance from the foreign body increases, the degree of distortion decreases.

The extent of the field distortion depends on several factors. The most significant are the size of the object which is to be located and its permeability. The larger the object is, the larger the distance is from which it can be located.

If the object is magnetized in the ground, i.e., if it has its own magnetic field, the lines of magnetic flux react in accordance with the polarity of the body. The north pole of the object repels the lines of the earth's field, whereas the south pole of the object attracts them.

The total interference is usually larger than that of objects which do not create an external magnetic field, but in rare cases it can be smaller, depending on the position of the object. This shows that with the help of a detector which enables one to identify distortions of the earth's field, which is essentially homogenous, it should be possible to track down hidden pieces of iron. A differential magnetic device for measuring field intensity is the preferred instrument for this task. In such a device, two magnetic field sensors are aligned geometrically at a prescribed distance from one another and connected electrically in such a way that the magnetic field intensity measured at the location of both sensors results in an output voltage of zero when the field intensity which impacts the location of both sensors is identical. This is the case in the homogenous earth's field. Distortions of the earth's magnetic field which are caused by the piece of iron which is to be located cause the magnetic fields which impact the locations of the two sensors to differ in terms of magnitude and direction. In this case the measurement set-up creates a voltage which is proportional to the difference in field intensity. With the help of a field computer, the signals created by the voltage can be recorded and processed using evaluation software.

The measurement evaluation is performed by systematically traversing a surface at distances of 0.5 m (so-called SPUREN). Then the evaluation is performed using EVA2000, with the results being depicted on the field maps.

Electromagnetics: Measurements performed by Geohydraulik Data using TDEM

The geophysical measurements were taken using the Time-Domain Elektromagnetic (TDEM)-procedures developed by Geohydraulik Data *GdbR*, Körnerstr. 2, 55120 Mainz. On two days (Sept. 6 and 7) this procedure for detecting metal bodies and explosive ordnance was used alongside the procedure elucidated above. According to Geohydraulik Data, it is possible to detect potential dud bombs at depths of up to 10-15 m under ground level. One advantage cited is the minimal impact on foreign bodies located near the surface (construction waste, conductive topsoil, armed cement, pipelines and conduits, fences, etc.). On the other hand, high resolution is cited as a feature. The measuring principle is as follows (as stated in the brochure supplied by Geohydraulik Data): TDEM is a surface-geophysical deep sounding method. A TDEM system consists of a transmitter-receiver-coil (TRC), a control unit, which is needed to generate signals and record signal responses, as well as an integrated PC used to record and store data. During a TDEM investigation using a grid the vertical distribution of electric features in the underground are measured at every sounding point. The distribution of the receiver voltages is depicted within so-called time slices, which provide gauges for a relative depth assessment. Nearby metal bodies generate high, laterally limited voltages whereas metal bodies which are farther away as well as conductive parts of the underground generate medium-range voltages and undisturbed low-conduction areas generate weak voltages.

The signal generated by the control unit in the transmitter-receiver-coil generates a primary electromagnetic field which creates eddy currents in the underground. These in turn create a secondary electromagnetic field which is detected by the TRC. The intensity of the secondary electromagnetic field at any given time is dependent on the distribution of electric conductivity in the underground. With increasing time, the eddy currents extend deeper down into the underground as well as extending laterally, creating „smoking rings“ in the process. Thus signals registered early map areas near the surface whereas signals registered later on generally map deeper areas.

In other words this means that the TDEM method generates a pulsed primary magnetic field via a transmitter cable (loop) which induces eddy currents in metal bodies located in the underground in particular. These in turn generate a secondary magnetic field which is measured as transient voltage in the same cable loop, which is now used as a receiver antenna. As time progresses, the increase in depth effect is registered.

A complete depth sounding with 32 transient voltage values was performed at each measuring point. The system employed, TDEM 2000 by BISON, is equipped with 32 channels with 96 time domains to choose from. The time needed for cyclic current turn-offs is less than one micro-second. The grid measurements were taken using a special indoor antenna. A one-meter grid was used, i.e., 100 measuring points were defined and measured per testing field. The results were also depicted on field maps.

Results

Unterground conditions

In all excavations, fillings consisting of cohesive soil were found near the surface. Such fillings usually have a low proportion of construction waste, brick and scoria and are identifiable as Keuper material, in part with chunks of red, gray and greenish sand-, silt- and mudstone.

Quaternary sedimentation was found at depths between 1.5 and 2.5 m. It consisted of muddy alluvial clay with varying proportions of organic substance.

Results of geophysical measurements

Results of measurements taken by the KMBD (magnetometer)

The KMBD documented their results as follows:

„On Sept. 6 and 7, 2006 a search using a gradiometer (i.e. a magnetometer; the author) was carried out on the abovenamed property by the Explosive Ordnance Disposal Agency on 10 predefined testing fields. The search was performed, evaluated and documented using computer assistance.

The search with gradiometer and the ensuing evaluation were impeded by foundations, pipelines and conduits, tracks, trackbed gravel and metal columns. The evaluation of the testing field yielded differing soundable depths. With the help of an excavator the testing fields were cleared of foreign bodies. No ammunition or parts of ammunition were found.“

In correspondence to the results for the individual testing fields the boundaries of the so-called interference fields differ, which is to say, after the anthropogenic filling was removed it was possible and purposeful to sound out the depicted depths with a magnetometer.

Results of measurments taken by Geohydraulik Data (electromagnetics)

The results of measurements taken by Geohydraulik Data were reported as follows:

“The abnomalies which are to be attributed to metal objects visible on the surface were taken into account in the evaluation and are designated as such in the abnomaly plans. As concerns unknown object locations (UOL) in testing fields T3 and T2 the objects constitute relatively large metallic bodies at a medium depth (approx. 2-4 m under top ground surface). In the area of testing field T4 relatively large edaphic abnomal surfaces were identified. After the scoriaceous sediments in this area were removed, no further significant

anomalies were found on the testing field. The UOLs in the area of testing field 10 are all small and near the surface. Thus all the other investigated areas can be considered free of any large metal bodies up to a depth of approx. 6 m under top ground surface.“

After further targeted excavations the UOLs in testing field 2 were identifed as train tracks. The UOL in testing field 3 was revealed to be a cast-iron drainage pipe. In this case, as opposed to the measurements taken with the magnometer, the boundaries of the various interference fields are close to the surface with the exception of testing fields T1 and T3 (in correspondence to the prepared testing fields at depths of approx. 0.6-1 m). As Geohydraulik Data *GbdR* states, it would be possible to take measurements of the original surface while leaving the surface pavement intact.

Results of cleared testing field excavations

In Table 1 below, the excavations which resulted in the course of setting up the testing fields are depicted.

Value assignment in accordance with LAGA	**Amount in [t]**
Cement, uncontaminated	262.16
Asphalt, containing tar	107.81
Soil Z1.2	383.72
Soil Z2	780.0
Construction waste Z2	846.6
Trackage gravel >Z2	282.78

Table 1: Cleared excavation material

In correspondence to the assignment values in accordance with LAGA (*Länderarbeitsgemeinschaft Abfall*), only contaminated materials – with the exception of cement used for building foundations – were found. In particular, PAH substances were responsible for the contamination. Of secondary significance were heavy metals in relatively large concentrations.

Evaluation

Preliminary remarks

In correspondence to the standards set for healthy living and working conditions as laid down in German building law, appropriate precautionary measures must be taken when properties with potentially hazardous areas are built up again. Furthermore, when properties which carry the risk of containing explosive ordnance are sold, reduced monetary revenue is expected. This fact is founded on additional, albeit not precisely definable technical measures which prove necessary during the rebuilding process.

Therefore explosive ordnance clearance of properties for which higher-value usage is planned for the future constitutes a measure required by law to ensure a healthy living and working environment, a strategy to ensure that the property can be marketed advantageously and lastly, a measure which promotes such properties' valorization. Therefore in the case of the REVIT project the principle necessity for explosive ordnance clearance measures is undisputed.

There is knowledge of underground contamination on this area which, due to the long years of near-surface usage which has promoted contamination, encompasses a large surface area. Thus any intervention into the underground calls for excavations which usually cannot be replaced. The anticipated results are contaminated material which must be disposed of and the need for refilling with uncontaminated material.

This constitutes precisely the goals of the measures presented here: a procedure for detecting explosive ordnance in the underground is to be found which enables one to declare with relative reliability that the area in question is free of explosive ordnance while limiting the efforts (excavations) needed to achieve this. Moreover, the procedure should prove suitable in terms of the efforts needed for the actual measurements (expenditure of time, preparation of the surface, marginal conditions).

Evaluation of both measuring procedures

The efforts required to measure a certain area differ in terms of the two systems. The testing fields were measured using both methods on two consecutive days. The actual measurement-taking process takes three to five times as long when using the electromagnetic system as it does when the magnetometer system is employed. According to the KMBD, the daily capacity lies between 5,000 m^2 and 10,000 m^2 maximum, providing the measuring points have already been determined (manpower requirements: 2). When the electromagnetic system is used, a daily capacity of approx. 1,000 m^2 is realistic (manpower requirements: 2).

The two methods in question are comparable in terms of conclusiveness, but in the case of the electromagnetic system limits are placed on the obtainable degree of resolution in regard to metal parts detection. In view of the case at hand, which involves the detection of relatively large explosive ordnance, this disadvantage is insignificant. The overall accuracy of this method is lower than that of the magnetometer method, however.

On the other hand, the system employing electromagnetic measurements can be used for areas with sources of interference (for. ex. relatively large, laterally positioned metal parts near the surface, vestiges of building foundations, trackage gravel etc.). Measurements using the magnetometer are only conclusive if sources of interference are removed before the measuring process is performed. The obtained results are highly reliable, however. Thus measurements using the magnetometer call for more labor input, in this case earth-moving work necessary to perform the measurements, but they also elicit results with a higher degree of reliability and accuracy. In contrast, measurements using the electromagnetic system can easily be taken under current conditions while leaving the surface intact, albeit with certain limits being placed on their conclusiveness.

Criterium	Magneto-meter	Electro-magnetics
Time expenditure for measurements	+	-
Necessary preparation (elimination of sources of interference / excavation)	-	+
Conclusiveness/ accuracy	+	0

Table 2: Matrix for evaluation of both measuring procedures

Conclusion

On the basis of the ascertained boundaries of interference fields (in this case in relation to magnetometer measurements) and current usage of the area in question, partial areas can be identified from which both kinds of information can be elicited, thus providing a basis for typization in connection with explosive ordnance clearance. The boundaries of interference fields determined within the testing fields have been transferred to larger areas.

When deriving the average excavation depths for the various types of surfaces the following factors were taken into account:

- The historical development of the surface
- Results of building fabric investigations for individual buildings in connection with demolition plans;
- Results of the investigation of the testing fields.

Six types of surfaces can be distinguished which can be characterized in terms of boundaries of interference fields. These interference fields representing the average excavation depths when using the magnetometer system. Ultimately, these features should be taken into account when making decisions as to which method is more suitable for the task at hand. Apart from types of surfaces which require only negligible efforts in preparation of geophysical measurements needed for explosive ordnance clearance, certain types of surfaces can be identified which, due to the existence of building structures or other far-reaching sources of interference, call for considerable efforts of this kind. The time and effort required also pertain to the high disposal costs.

Scenarios for explosive ordnance clearance

When the methods elucidated above and the types of surfaces which they are used for are considered in terms of individual scenarios for the explosive ordnance clearance of the area in question as a whole, the following assessment can be made:

Scen-ario	Propor-tion of cleared surface area in [%]	Neces-sary excava-tion (approx.), in THSD [t]	Accuracy
1	100	690	Very high
2	80	274	Very high for some areas, moderate for others
3	60	469	Very high for some areas, uncertain for others
4	60	73	Moderate for some areas, uncertain for others

Table 3: Overview of scenarios

It is evident that an explosive ordnance clearance of the entire area which guarantees a high degree of accuracy would be connected with unreasonably large efforts. The costs incurred on the basis of the four scenarios depicted above lie between 2.1 mill. € (Scenario 4) and 18 mill. € (Scenario 1).

References

Bundesrepublik Deutschland: Baugesetzbuch, Status: Sept. 5, 2006.

Landeshauptstadt Stuttgart Sprengbomben, andere Kampfmittel-Altlasten und deren Beseitigung in Stuttgart 1945 – 1998, Landeshauptstadt Stuttgart, Schriftenreihe des Amt für Umweltschutz – Heft 7/1998.

Ertel, Th., Koning, E., Bärlin, M., Schug, B.: Flächenmanagement und Liegenschaftsrecycling, Terra Tech 11/06

GEOCON-AER GmbH, 2006 Stuttgart: Untersuchungen zur Kampfmittelproblematik auf dem Gesamtareal in 70372 Stuttgart-Bad Cannstatt, unpublished