TESLA - THE RANGE OF SURVEY AND ALIGNMENT WORK

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1. INTRODUCTION

A superconducting electron-positron linear collider (TESLA) of about 33km length with an x-ray free electron user facility is currently being planned and developed by an international collaboration at the Deutsches Elektronen-Synchrotron DESY. For the realization of the TESLA project a lot of basic survey and geodata are necessary and requested by design and construction. To operate the accelerator successfully a very high accuracy is required during installation and future service periods.

2. FIRST GEODETIC APPROACH

In order to stake off any installation of a planned facility basic networks have to be established. Usually networks for horizontal position, height and gravity are needed to form the basis for construction engineering of large facilities. Since a specific TESLA reference system doesn't exist yet and can't be established before the legal plan approval procedure has been done the public reference network of Hamburg and Schleswig-Holstein has to be used for the first topographic approach.

In order to possibly realize the THERA option [5] the TESLA main linac has to be built in prolongation of the western straight section of the HERA proton machine and therefore has to be in fixed relation to the HERA reference system. In a first step the relation between the HERA reference system and the public reference net has been examined by a GPS campaign in cooperation with the Bauhaus University Weimar. In this campaign 4 main HERA reference points (1103, 2102, 3101, 4103, see fig. 1), 15 public survey pillars along the route of TESLA and 2 SAPOS reference stations (public GPS reference stations) [1] have been observed.

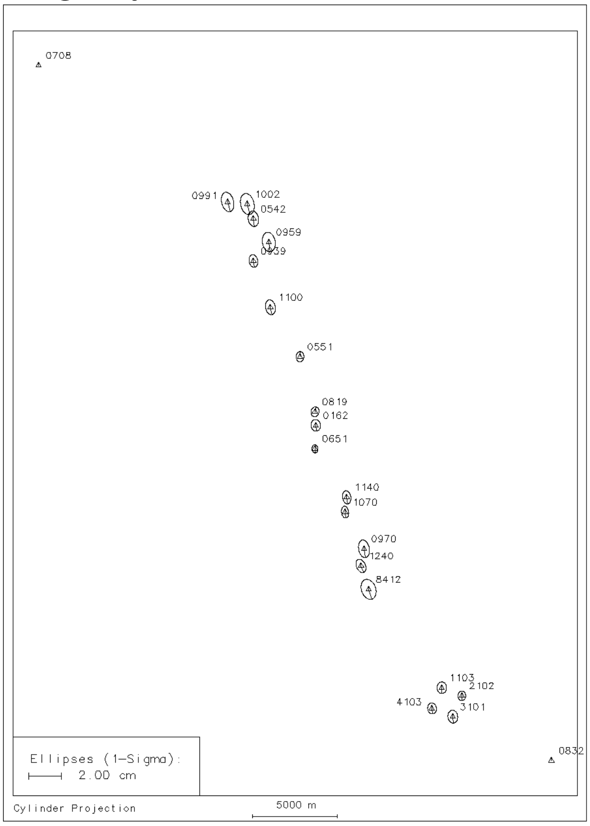

Fig. 1: Calculated error ellipses for GPS campaign

The results of a calculation [6] show radii between 0,6 and 1,3cm of the 1-sigma error ellipses, which reveals the internal accuracy of the GPS-network when using two ETRF89 reference points (0708, 0832, see fig. 1) as geodetic datum (ETRF89: European Terrestrial Reference Frame). The displacement vector of corresponding points in the HERA coordinate system and the public network is within the range of 5 to 15 cm, depending on the quality and accuracy of the public survey pillars. Thus the public coordinates show sufficient accuracy to work as a reference for topographic measurements but not for construction.
Since some topographic maps along the TESLA route show poor accuracy (1-2m) it was decided to carry out topographic measurements for each construction site in order to create exact maps as basic documents for planning and later call for tenders. The topographic survey has been started in January 2002 and the measurements are nearly done by now.

An aerial photographic flyover of the complete route of TESLA in order to collect more topographical base data for plan and map productions and the referencing of the application data is already planned and will be executed in late november. Digital orthographic photographs (orthophotos) of a band of 1200m width along the route will then be available. An altitude computation including roof edges and topographic edges will be done for every construction site and within a band of 100m width every 10m along the route resulting in a digital 3D-surface model. Up to now first visualizations of the route or the construction sites have been done with oblique aerial images (see fig. 2)

Fig. 2: Visualization and map of main linac and damping ring at a planned construction site

2. BASIC NETWORKS

Usually the calculations to stake off planned facilities are not based on a 3D-coordinate system, but are done separately for horizontal position and height. For tunnel construction one has to assure that the 3D-axis of the tunnel can be built with the demanded accuracy. The network subdivides into an overground part that runs along the route of the tunnel and mainly connects the subnetworks at each construction site (halls or shafts) - and a subterranean part that controls the tunnel driving.

The main network consists of main pillars at each construction site. To connect the construction sites, reference points and supporting main pillars along both sides of the route will be used. At each construction site there have to be 2nd order points to orientate direction measurements. For the subterranean network the coordinates have to be transferred via the shafts or halls at the respective sites (see fig. 3).

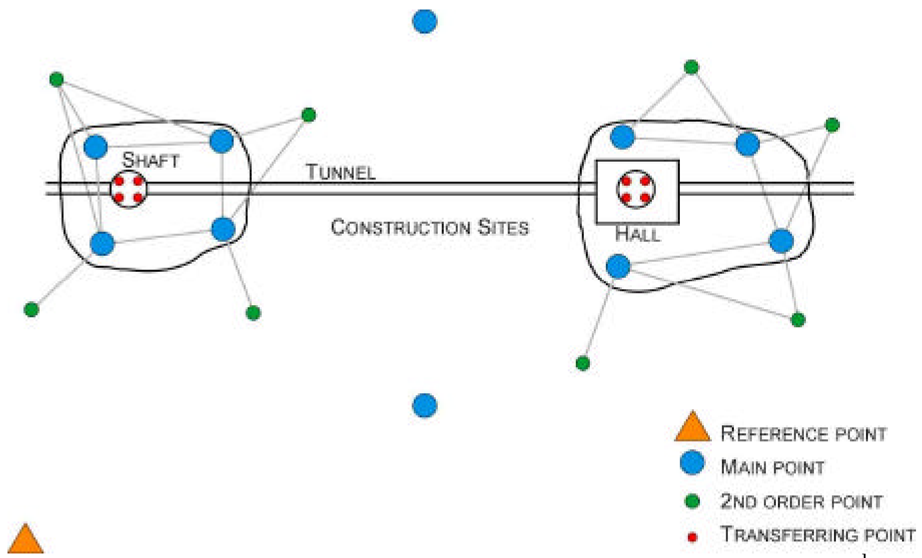

Fig. 3: Example of a surface network with reference points, main points, 2nd order points

The horizontal coordinates (2D coordinates) of the surface network will be determined efficiently via “survey grade” GPS-methods. The height reference network has to be refined by means of precise leveling. The demanded global precision (standard deviation) of every reference point in the whole area of the planned linear collider has to be better than 5mm. Reference points and main points on sites and along the tunnel have to be monumented by concrete pillars with a centering device and benchmarks for height. A GPS network could be based on the following concept: Three permanently recording reference stations of the National Survey Network, four additional reference points of the Federal State Reference Frame (SH-REF, Schleswig-Holstein Reference Frame) and the above mentioned supporting main pillars along the TESLA route (see fig. 4) will be used to set up the reference net. The permanently recording stations are located at distances of 8 to 12 km to the respective construction sites. The SH-REF stations are spaced at intervals of 20 to 25 km and are located at distances of 6 to 20 km away from the TESLA route. The number of sessions depends on the quantity of applicable GPS receivers. The outcome of a rough calculation is 21 sessions when using 8 receivers. More exact calculations with a simulated net are in the works.

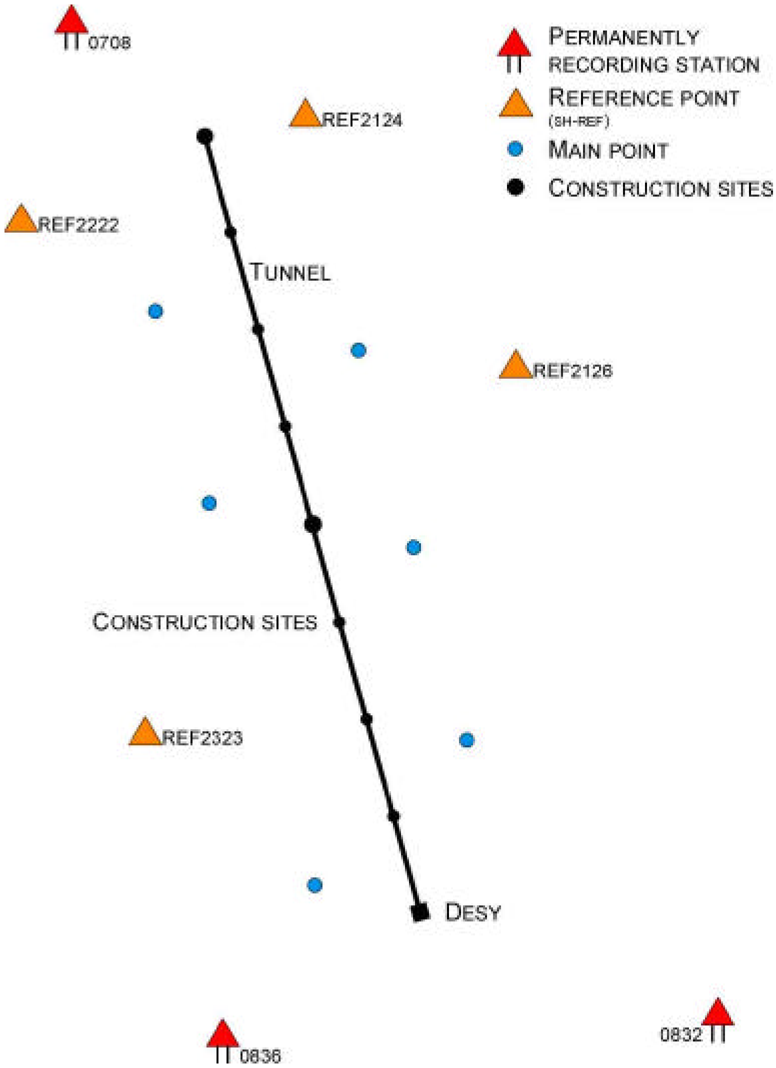

Fig. 4: Example of main GPS network

The third basic network to be established is a gravity network. Since all survey methods especially height measurements are referenced to the geoid and thus depend on earth's mass distribution whereas particles in an accelerator aren't influenced by mass-forces, short wave geoid undulations have to be detected. Short wave geoid undulations may lead to an undulating alignment of the machine which - depending on amplitude and wavelength - may have an adverse effect on beam quality. Based on known geological parameters analyzed in an expert's report on foundation soil along the TESLA route an estimation of expected geoid undulation is in the works. Additionally - in cooperation with the 'Institut für Erdmessung' of the Hannover University - astro-geodetic and gravimetric methods are under examination to prove their applicability to acquire undulations of the geoid with the demanded accuracy. E.g. a zenithal camera with an effective accuracy of 0,1 arcsec will be able to detect undulations of approximately 0,1 mm at a wavelength of 600 m.

4. REQUIREMENTS FOR SURVEY AND ALIGNMENT

4.1 Concept of a Survey Procedure

The reference points which have been transferred from the basic overground network into the tunnel have to be refined in order to match the demanded accuracy for the alignment of the beam transport system. The standard deviation of every component of the beam transport system is postulated to be within 0.5mm horizontally and 0.2mm vertically over a range of 600m (betatron wave length 576m) [2]. Since there are several separate beam lines to be aligned with high accuracy, the most efficient survey will be carrying out a two step procedure. The first step is carrying out a reference alignment to provide a suitable reference structure. The second step then is to transfer the coordinates by connecting each beam line to the reference structure.

4.2 Functional Prototype of the Reference Survey System

The DESY survey group decided to use a multipoint alignment method for most areas of the tunnel to provide an exact horizontal position of the reference structure in the tunnel. A hydrostatic levelling system (HLS) will be installed to provide the exact vertical position of the reference points. The principle of a multipoint alignment and the HLS have already been presented at the 5th IWAA in 1997 [10].

Alignment methods in general use a straightness reference to which distance measurements to objectpoints are related. The straightness reference could be a stretched wire or a laserbeam in an evacuated tube.

The prototype of the reference survey system developed by a cooperation of Bauhaus University, SLAC and DESY [4] consists of a train with six carriages which support the various sensors for distance measurements between straightness reference and reference points, inclination and detectors for the longitudinal position of the train. Each carriage has its own supply unit. Two stretched wires form the straightness reference (see fig. 4). For details see talk by Andreas Herty on high precision 2D horizontal alignment [3]

By a HLS the heights are referenced to the geoid respectively earth's gravity field and thus the reference structure follows an equipotential expanse. For those areas of the tunnel, in which the components should follow a geometrically straight line (X-Ray Free Electron Laser, XFEL), for geometrically straight LC designs such as NLC or for areas in which the linac changes elevation a different height measurement system than a water surface may be more convenient. Since the University of Oxford LiCAS group already developed high accuracy straightness and distance measuring techniques, they will develop a prototype with a combination of laser straightness monitors and frequency scanning interferometry (FSI) that adapts the same mechanical structure developed by DESY for the stretched wire system. See talk by Ankush Mitra on The Linear Collider and Alignment Project for details [7].

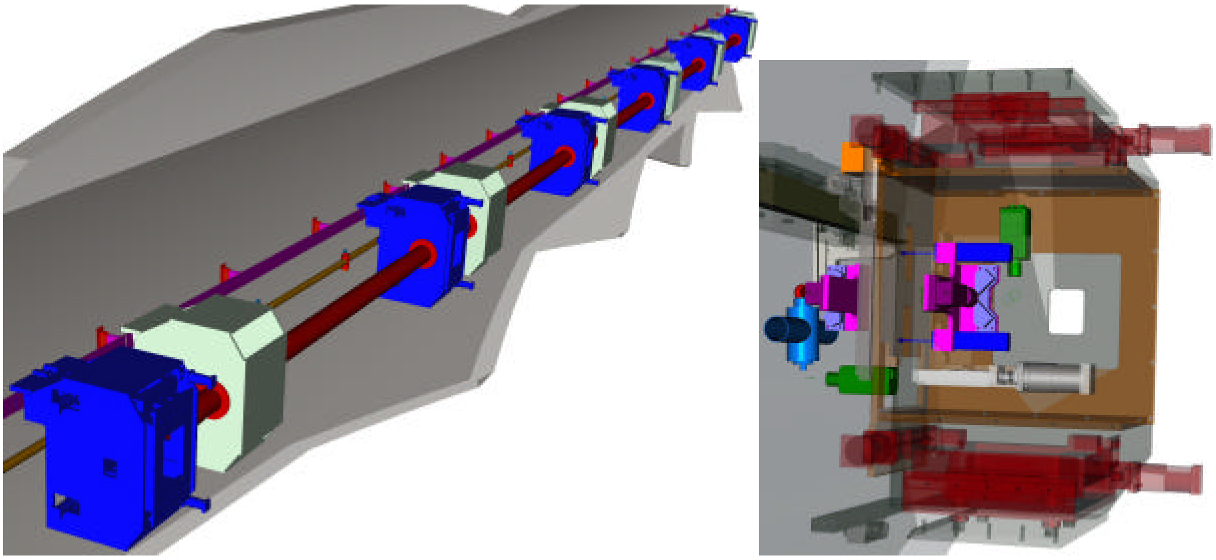

Fig. 4: Design of survey train and single carriage with various sensors

The schedule for the DESY survey and alignment system is based upon the alleged schedule for the construction of TESLA resp. XFEL. At the beginning of assembly there has to exist a functional survey and alignment system complying with the demanded accuracy.

A functional prototype of the survey system has to be established by the end of 2004. The first prototype of a single carriage and a dedicated test tunnel for the survey system will be available at DESY by February 2003. By end of 2003 a first prototype of the survey system which has to consist of at least 3 carriages, should be available. Testing will then cover a period up to August 2004. All testing should be done by the end of 2004.

4.3 Transfer of Alignment to Machine

Since the tunnel is expected to move on scales relevant to the alignment of the machine, it is important that prior to transferring the coordinates from the reference structure to the machine the wall mounted reference structure is examined. By repeating the reference alignment one has to assure that the tunnel is stable enough to align the machine. This means that the proposed survey system has to be capable of automated, fast and repeated measurements in particular during the early years in which the tunnel will move more then later. In each service period the first thing to do is repeating the reference alignment prior to adjusting the components of the linear collider. The following pictures show a first prototype of a carriage for the transfer of the alignment structure to the components of the TESLA linac. This assembly may be pivoted in any emergency situation. The reviewed prototype will be optimized in shape and size.

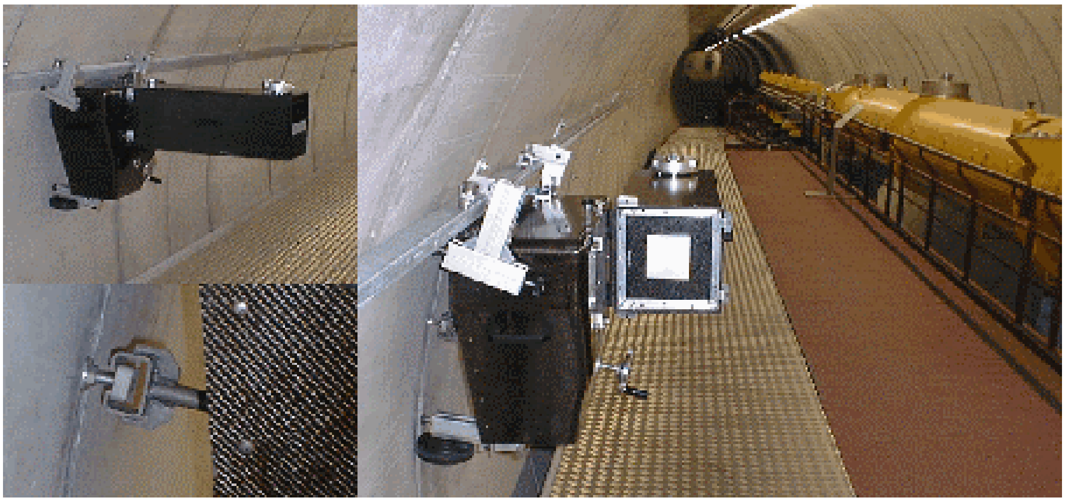

Fig. 5: Photographs of wall mounted carriage for transfer of coordinates and details of fixation clamp

4.4 Free Surface Hydrostatic Levelling System

A hydrostatic levelling system will be installed in the horizontal part of the tunnel in order to provide an exact vertical position of the reference points. Basically this can be done by installing a sealed pipe half filled with fluid, half with air. The surface of the fluid levels to an equipotential expanse and thus serves as height reference. With capacitive or ultrasonic sensors the clearance between reference point and the surface of the fluid can be determined. First tests of a 42m installation with capacitive sensors (see fig. 6) led to contenting results. The above mentioned distance sensors show an accuracy of better than 5 m.

It has been decided to exchange the capacitive sensors by ultrasonic sensors (see fig. 7) mainly due to better calibration possibilities but also due to cost effectiveness. Various diameters of the tube have been examined. A 1km installation has been under examination from February 2001 to October 2002 in an adit near Katzhütte (Thuringian Forest) originally built to lead water to the

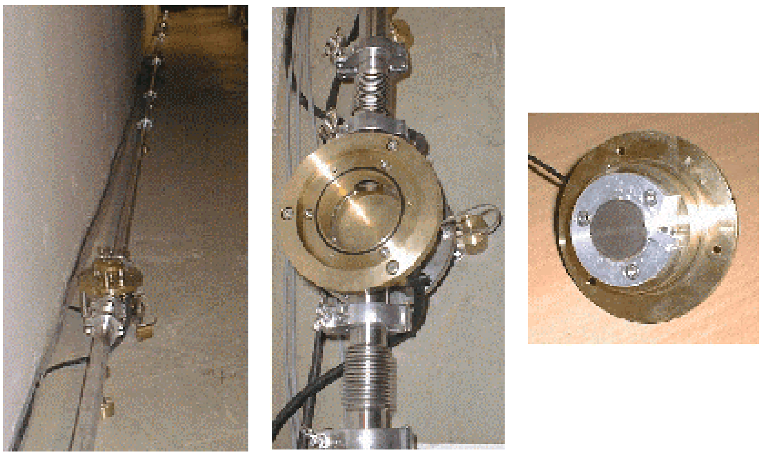

Fig. 6: Photographs of a test installation (42m section) of a hydrostatic levelling system with capacitive sensors

Leibis/Lichte dam. The ultrasonic sensors show an accuracy of better than 10µm. With the final setup the height of the reference points can be determined to 0.1mm along a 600m section. See talk by Markus Schlösser on high precision vertical alignment for details [9]

Fig. 7: Photographs of prototypes of new package for ultrasonic sensors

3. Specific Measurements

Some specific measurements have to be carried out in preparation of the construction of TESLA. For example, the projected tunnel underpins a baroque church which is under monumental protection. The height of the tunnel axis is 8m below zero, top ground surface at the church area is between 10m and 11m. This results in a clearance of about 14m between the top edge of the tunnel and the foundation of the church. An expert's report [11] on foundation soil in the church's area predicts a settlement of about 10mm at the centre of the 20m wide settlement area along the route while driving the tunnel. A second expert's report on the static structure of the church predicts movements of parts of the building in the order of 10mm which are regarded as noncritical. Nonetheless the effective settlement of the church has to be examined accurately while underpinning that area. The predicted settlement area should be verified before while driving the tunnel at some other regions.

Intensive monitoring of the church started back in September 2001. The church has been equipped with height benchmarks and a first precise leveling was done to establish the height network (see fig. 8).

Additionally a 3D reference network for deformation measurements consisting of 7 reference points has been established, 5 of which are composed of concrete pedestals, the other two are brass bolts (see fig. 9). Since the church and the reference network lie in the center of a historic town, massy concrete pillars must not be utilized. Instead of that concrete pedestals with a centering device for attachable aluminum cast pillars have been designed (see fig. 9). The concrete pedestals are installed below top ground surface and can be covered with a cap when not in use.

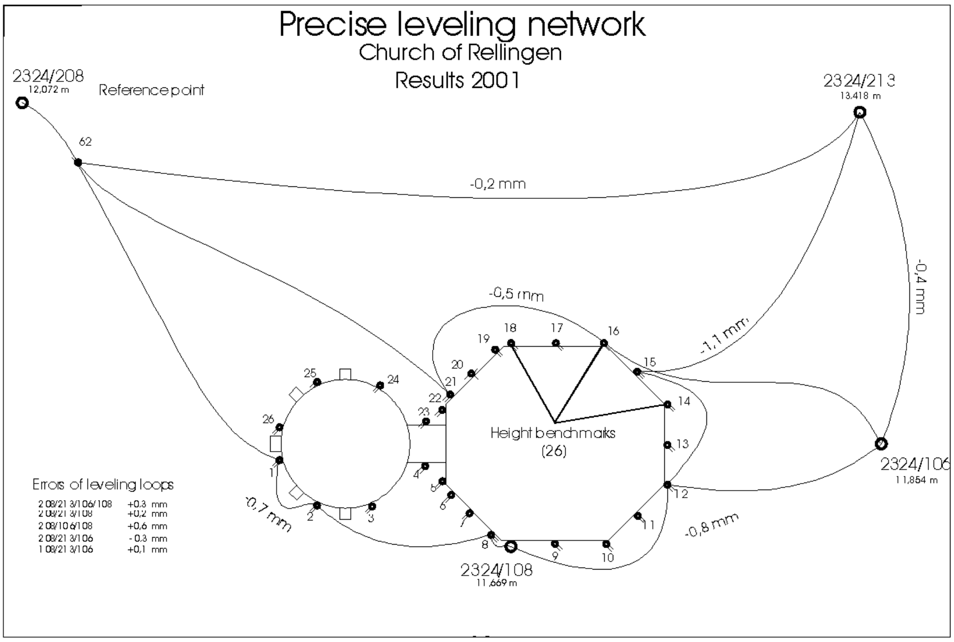

Fig. 8: Results of precise leveling

Using this 3D reference network two examinations on deformation and settlement of the church have already been done. The first measurement took place in November 2001. In this first examination the complete structure of the church has been acquired geometrically by means of contact-free distance and angle measurements with a tacheometer. In total there have been acquired more than 1100 object points at the exterior and interior of the church. A repeated examination took place in April 2002. The comparison of identical object points of both epochs only reveals variations of 3D position in the range of 0 to max. 5mm, which shows good conformity with the expert's report [12] on static structure of the church already done in 1999. The forthcoming examination is scheduled for early December 2002. The monitoring of the church will be continued two times a year within the near future. If further on the static structure shows no movements the examination interval can be extended to once a year.

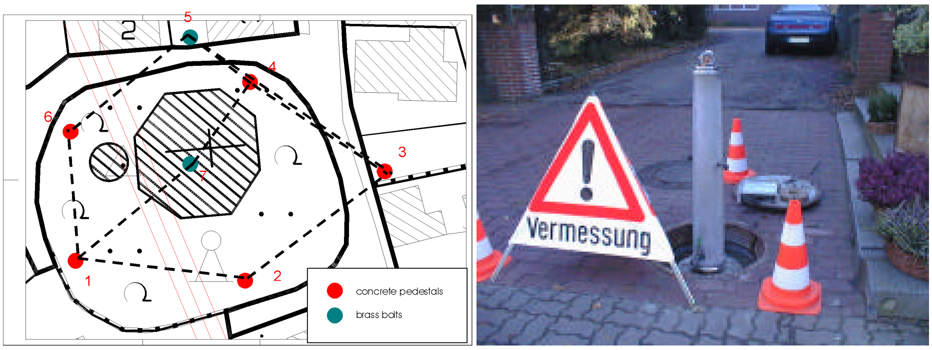

Fig. 9: 3D Reference network and photograph of pillar on pedestal

5. Conclusions

After presenting the Technical Design Report to the German Science Council (Wissenschaftsrat), which is an advisory body to the Federal Government, every concerned group of DESY has started with detailed planning for TESLA. For the survey and alignment group the goals for the next years are simple to describe:

- To provide all required survey data for design and construction
- To find economic solutions to guarantee required accuracy in aligning thousands of components.
- To present solutions for survey and monitoring of TESLA in different geometric aspects during operation.

To cover these fields of survey and alignment, all capacity of the group will be necessary in the next future, including additional co-operations with related research institutes, accelerator centers or universities, which will be requested to take part in the project. The following special areas and tasks are in the works and further to explore:

- General, terrestrial base network, 33 km, GPS & classical geodesy
- Detailed Geoid modeling, 33 km , leveling, gravimetry
- High precise position and leveling system in the horizontal part of the main tunnel, 26 km
- High precise position and leveling system in damping ring locations, 17 km
- Leveling system for non-horizontal sections of the main tunnel, 3km
- Position and leveling system for the partially inclined and geometric straight tunnel of the X-Ray FEL with 10 photon beam lines, 5km & user facilities
- Central experimental zone, two high energy experiments

After the positive review of the TESLA project in July 2002 by the German Science Council (Wissenschaftsrat) [13] the decision of the Federal Government is expected for 2003.

6. References

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