Preparation of utility maps of cities using advanced technology

Sanjay Rana
Managing Director
IGG Services (P) Limited

Abstract:
Trenchless technology is being used for laying of pipes and cables in India at an increasing rate. The successful use of this technology, and benefits in terms of speed and least inconvenience to people, are well known. One of the problems being faced, however, is the damage to existing utilities in the process. The rate of such damages is especially high in India due to missing utility records and unavailability of a one-point contact where database of existing utilities is available.

Technological advancement in the fields of GIS, Remote Sensing and Geophysics provide an answer to the problem. Using these techniques it is possible to create accurate maps of the area, with information on underground utilities, to decide on important aspects like alignment, safe depth etc. Present paper discussed various tools available for mapping (GIS & Remote Sensing) and non-destructive detection of underground utilities (Ground Penetrating Radar etc.).

Introduction:
Population explosion and resulting demand of appropriate infrastructure facilities are posing serious challenges for the administrators and planners. Trenchless technology has emerged as a major technique for laying utilities without opening trenches. The data on existing utilities however is of utmost importance to avoid damage to existing utilities and safety of personnel. Effective management and planning requires updated maps and information. Recent developments in the area of Science and Technology have provided powerful tools such as Geographical Information System (GIS), Global Positioning System (GPS), Remote Sensing and Geophysics (including Ground Penetrating Radar). These advanced technologies can very effectively be used to handle the present day complex problems related to optimum utilization of available resources and infrastructure. Today it is possible to create on 1:1000 scale Digital Map using high resolution (one meter) satellite imagery and preparation of GIS database in same scale using State Of The Art GIS technology. Further geophysical tools such as Ground Penetration Radar (GPR) can be used for the accurate mapping of the underground infrastructure facilities (Electrical & telecommunication cables, pipelines etc.) to be placed on these maps accurately, rather than relying on historical data, which more often than not is incomplete and inaccurate.

What is GIS?
In the strictest sense a GIS is a computer based program capable of assembling, storing, manipulating and displaying geographically referenced information i.e.; features existing on the ground and their attribute information. Maps and attribute data are stored systematically in this system so that GIS makes it possible to perform following complex analyses:

- Information retrieval: Any required specific information could be retrieved at will from the huge database using simple query operations.
- Overlay: Relationship between various layers (administrative boundaries, buildings, road, rail, and other infra-structural facilities) can be determined.
- Data output: A critical component of a GIS is its ability to produce maps on the screen or paper, which convey the analysis results for the planners and administrators to take decisions. Using GIS planners and decision-makers can map quantities, densities, find what is inside, what is nearby and change detection.

Remote Sensing:
National Remote Sensing Agency (NRSA) is involved in the Aerial surveys using variety of satellites for more than last 25 years. NRSA is continuously receiving satellite data on various resolutions. IRS-1C PAN and LISS-III data has been used extensively by the planners and decision-makers in the past for micro level planning.

Recently NRSA has started selling 1-meter resolution satellite data of Space Imaging (IKONOS). This high-resolution satellite data has added the higher degree of accuracy in the mapping. Small features such as road dividers, buildings, ponds etc. can be identified very easily.

Base Maps Preparation:
Preparation of a reliable basemap is the first step towards data management. Using the tools of GIS and Remote Sensing, base maps can be prepared in a speedy and economical manner:

- Satellite Data of 1-meter resolution (IKONOS) can be purchased from NRSA.
- Satellite images are then registered in the required projection system so that digitized output is achieved in the real ground units.
- Satellite images are digitized in the different layers depending upon the variety of features available on the ground.
- Topology of the various features digitized are created so that actual attribute information of the corresponding feature on the ground can be linked to it.
- Ground surveys are conducted to update the features, which are not visible on the satellite image (Transformers, manholes, electrical poles, telephone poles, etc) and to collect the actual names of the buildings, roads, etc.
- Ground survey data are integrated with the attribute table of the corresponding feature.

Subsurface Utility Engineering:
Most of Indian cities have an extremely complex network of utilities, typically characteristic of a developing country. The records on existing utilities underground are either simply non-existent or inaccurate. With ever-increasing use of trenchless technology, requiring accurate information on underground utilities, accurate techniques for non-destructive detection of such utilities are extremely important. Poor records, improper notification, and excavation errors all contribute to making subsurface utility breaks an often costly but preventable problem. Subsurface Utility Engineering (SUE) is a discipline dedicated to the determination of the exact location of existing underground facilities. Use of SUE makes sure that utilities are accurately picked up and plotted on site plans. This in turn reduces costs, delays, and public inconvenience. In addition, by eliminating the risk of utility breakage, the project will be safer for both construction personnel and the general public, hence reducing liability concerns. Subsurface Utility Engineering, or SUE is a new discipline that utilizes modern techniques to detect underground utilities in a total non-destructive manner. This process results in a digital map that will identify utilities within the project area.

Indian experiment with trenchless technology has been very encouraging, except for the damages to existing utilities, causing inconveniences and heavy costs. Information obtained from other sources such as municipalities, is rarely accurate enough safe borepath determination. In addition, depth information is almost never available. Most of the information on past utilities has never been documented in systematic manner. SUE contractors on the other hand gather the primary data, and prepare an accurate and precise location map. This not only provides great insight to the subsurface conditions, but eliminates the unknown variables and contingencies designers face everyday.

Various steps involved in data collection for existing utilities consists of various steps, starting from quick reconnaissance to detailed investigations. Various techniques used are:

Historical Utility Records Research

The data collection under this stage is aimed at obtaining basic information on possible locations, congestion and orientation of utilities. Such information is highly inadequate for use by trenchless contractor, but immensely useful for SUE contractor to plan density and orientation of survey lines, choose the right equipment, and plan the survey operations.

Designation

Designation is the process where by the approximate horizontal location of a utility is determined. Following a rough approximation of the general location of facilities provided by Historical records research and visual site assessment, a number of geophysical technologies can be used, selected by applicability, for identifying the horizontal locations of particular utilities.

Induction Utility Locators

Induction utility locators operate by locating either a background signal or by locating a signal introduced into the utility line using a transmitter. There are three sources of background signals that can be located. A utility line can act like a radio antenna, transmitting electromagnetic signals that can be picked up with a receiver. AC power lines have a 50HZ signal associated with them. This signal occurs in all active AC power lines regardless of voltage. Utilities in close proximity to AC power lines or used as grounds may also have a 50HZ signal that can be located with a receiver. A signal can be indirectly induced onto a utility line by placing the transmitter above the line. Through a process of trial and error, the exact above position can be determined. A direct induced signal can be generated using an induction clamp. The inductor clamp induces a signal on specific utilities. This is the preferred method of tracing, where possible. By virtue of the closed loop, there is little chance of interference with the resulting signals. When access can be gained to a conduit, a flexible insulated trace wire can be used. The resulting signal loop can be traced. This is very useful for non-metallic conduits. Finally, these signals can be located horizontally on the surface using a receiver. The receiver is moved across the estimated location of the utility line until the highest signal strength is achieved. This is the approximate horizontal location of the utility. The receiver is then rotated until minimal signal strength is achieved. This will give the approximate orientation of the utility. Vertical depth, however, derived from this equipment is subject to gross error.

Magnetic Locators

Ferrous Metal or Magnetic locators operate by indicating the relative amounts of buried ferrous metals. They have limited application to locating and identifying utility lines but can be very useful for locating underground storage tanks (UST's) and buried manhole covers or other subsurface objects with a large ferrous metal content.

Electromagnetic Surveys

Electromagnetic survey equipment is used to locate metallic utilities. This method pulses the ground and records the signal retransmitted back to the unit from subsurface metal. Particularly useful for locating metal pipelines and conduit, this device also can help locate other subsurface objects such as UST’s, buried foundations (that contain structural steel), and pilings and pile caps (that also contain steel).

Ground Penetrating Radar

Ground Penetrating Radar (GPR) is an electromagnetic method that detects interfaces between subsurface materials with differing dielectric constants (a term that describes an electrical parameter of a material). The GPR system consists of an antenna, which houses the transmitter and receiver; and a profiling recorder, which processes the received signal and produces a graphic display of the data. The transmitter radiates repetitive short-duration EM signals into the earth from an antenna moving across the ground surface. Electromagnetic waves are reflected back to the receiver by interfaces between materials with differing dielectric constants. The intensity of the reflected signal is a function of the contrast in the dielectric constant at the interface, the conductivity of the material, which the wave is traveling through, and the frequency of the signal. Subsurface features which may cause such reflections are: 1) natural geologic conditions such as changes in sediment composition, bedding and cementation horizons, voids, and water content; or 2) man-introduced materials or changes to the subsurface such as soil backfill, buried debris, tanks, pipelines, and utilities. The profiling recorder receives the signal from the antennae and produces a continuous cross section of the subsurface interface reflections, referred to as reflectors.

Depth of investigation of the GPR signal is highly site specific, and is limited by signal attenuation (absorption) of the subsurface materials. Signal attenuation is dependent upon the electrical conductivity of the subsurface materials. Signal attenuation is greatest in materials with relatively high electrical conductivity such as clays and brackish groundwater, and lowest in relatively low conductivity materials such as unsaturated sand or rock. Maximum depth of investigation is also dependent on antennae frequency and generally increases with decreasing frequency; however, the ability to identify smaller features is diminished as frequency decreases.

The various GPR antennas used are internally shielded from aboveground interference sources. Accordingly, the GPR signal is minimally affected by nearby aboveground conductive objects such as metal fences, overhead power lines, and vehicles.

A GPR survey is performed by towing an antenna across the ground along predetermined transect lines. The antennae is either pulled by a person or towed behind a vehicle. Preliminary GPR transects are performed over random areas of the site to calibrate the GPR equipment and characterize overall site conditions. The optimum time range settings are selected to provide the best combination of depth of investigation and data resolution for the subsurface conditions at the site. Ideally, the survey is performed along a preselected system of perpendicular or parallel transect lines. The configuration of the transect lines is designed based on the geometry and size of the target and the dimensions of the site. The beginning and ending points of the transect lines and grid intersection points, or nodes, are marked on the ground with spray paint or survey flags. A grid system is used to increase the probability of crossing the short axis of a target providing a more definitive signature in the data. The location of the antenna along a transect line is electronically marked on the cross section at each grid intersection point to allow correlation of the data to actual ground locations. The location of the targets can be marked on the ground surface using spray paint or survey flags.

Acoustic Location Methods

Acoustic location methods generally apply to waterlines. A highly sensitive Acoustic Receiver listens for background sounds of water flowing; (at joints, leaks, etc.) or to sounds introduced into the water main using a transducer. This method may have good identification results, but can be inaccurate. Acoustics can also being utilized to determine the location of plastic gas lines.

Non-Destructive Air-Vacuum Excavation

This information provides the highest level of accuracy presently available. It involves “locating”; the use of non-destructive digging equipment to expose buried utilities at critical points. When surveyed and mapped, precise plan and profile information is available for use in making final design decisions. The use of nondestructive digging equipment, particularly vacuum excavation, eliminates damage to underground utility facilities traditionally caused by backhoes. By knowing exactly where a utility is positioned in three dimensions, the designer can often make small adjustments in design elevations or horizontal locations and avoid the need to relocate utilities. Additional information, such as the composition, condition, and size of the underground utility, soil contamination, pavement thickness, etc., also assist the designer and the utility owner in making important decisions.

Non-destructive Air-Vacuum Excavation is used to determine the exact horizontal and vertical location of facilities. The process involves removing the surface material over approximately a 1' x 1' area at the electronically determined approximate horizontal location produced during the designation stage. The air-vacuum process proceeds with the simultaneous action of compressed air-jets to loosen soil and vacuum extraction of the resulting debris.

This process ensures the integrity of the utility line during the excavation process, as no hammers, blades, or heavy mechanical equipment comes into contact with the utility line, eliminating the risk of damage to utilities and personnel. The process continues until the utility is uncovered. Normally, the following information (if applicable) is recorded for each vacuum excavation: the utility type, material, size, depth, condition, location (x, y, z), orientation, roadway section materials and depths, soil type and water table.

Air-Vacuum Excavation can also be used at a proposed boring location to excavate below the "utility window" which is usually eight feet. This reduces the risk to utilities during the initial drilling process. Soil samples can be taken during the air-vacuum excavation process. Frequently, contaminants move along utility line trenches. Air-vacuum excavation can be used to obtain soil samples adjacent to utility lines without risking damage.

Data Management

Equipped with this EXACT information, the Data Management aspect of SUE can begin. These four categories of invaluable information can be utilized to provide extremely accurate subsurface "photographs" for designers. The unique blending of all four of these distinct procedures produces the most exact CADD map possible. After concluding the air-vacuum stage, the exact utility data is then translated into a computer generated three-dimensional map. This computer-generated map then becomes a critical weapon for the designer, allowing for exact instructions to be crafted for excavation. The sum total of benefits to the client when SUE is utilized is the virtual elimination of utility breaks and work stoppages, cost overruns, safety hazards, adverse publicity, and the ensured health and safety of the general public all related to subsurface utility breaks.

When all of these procedures are blended together and applied, a clear and exact visual representation of the position of underground utilities in an area of excavation is produced. Each of these tools, applied independently, offers a limited and only partial representation of the subsurface utilities. The benefits derived from the application of these procedures are maximized when each is fully utilized to complement one another.

The two-fold end result of performing a complete SUE survey is:

- A precise subsurface map that eliminates utility breaks, safety hazards or claims, and public outcry, and
- Confidence to provide the client or owner with the best product while reducing design cost and compressing schedules.

Why Use SUE?

SUE is no longer a novelty. SUE is now recognized by the American Society of Civil Engineers (ASCE) as a viable and necessary component for the practice of civil engineering. Their national standards activity, Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data, will have major ramifications regarding the allocation of risk for utility owners, constructors, and engineers. SUE will be a necessary process for every project designed by a civil engineer. The result will be that the reliability of utility data on plans is better defined.

Last Thoughts on SUE

- Did you know that no one really knows how many people are actually killed or injured every year as a result of utility breakage's?

- Did you know that today, many new projects are burying new facilities without creating actual "as-builts"?
- Did you know that in India we do not have legislation requiring a person to use one-call systems prior to excavation? However, there are few departments that require the contractor to obtain both the horizontal and vertical location prior to excavation?
- Did you know that on many projects, a "surprise discovery" rate of twenty-five percent or more is found, i.e., utilities not found on research or contract documents?
- Did you know that many training programs for directional drilling equipment does not mention that on projects where there is ambiguity or uncertainty regarding the contract plans and "one-call markout' a SUE professional should be considered as a safety precaution to find utilities?
- Did you know that on many major construction projects a designer is required to investigate the Subsurface Soil Conditions (geotechnical investigations) but very few consider investigating utility condition and use the owner's specification and plans?
- Did you know that many utility breakage's and interruptions have happened while a driller is performing a "geotechnical investigation"?
- Did you know that many utility breakages's occur during test-pitting operations while "searching" for the utilities?
- Did you know that the scrapes and scratches left on a pipe by mechanical excavation equipment could lead to the pre-mature pipe corrosion and possible failure? In June 1994, in US, an apartment building was destroyed by a gas line explosion because of such marks on the gas pipe.
- Did you know that most existing utility compilation plans are based on a compilation from random search of records and survey location of surface structures? (You are at a loss if a quick paving project has superseded the project.)
- Did you know that many communication companies do not provide copies of plans to surveyors, designers, and construction managers for utility location plan preparation?
- Did you know that budgetary cutbacks by municipalities and utility owners result in old documents not being revised to reflect current utility location?
- Did you know that incorrect information often winds its way into GIS System Networks?
- Did you know that Sue reduces liability? Use SUE to avoid being sued.

Indian Scenario:

Use of Ground Penetrating Radar (GPR or Georadar) is not new in India. Author himself has been involved in various projects using GPR for utility mapping since 1996, in India. GPR services are being used extensively by many trenchless contractors for obtaining prior information on existing utilities, which is an encouraging trend. A larger segment, however, is still operating without such information, resulting in costly damages to utilities. It is therefore required to arrive at a consensus among various service providers about making use of available technology to avoid damages and risks.

Like any indirect technique, GPR has its own limitations, and should therefore not be seen in isolation. Gathering of background information, use of additional tools discussed in the present paper and an understanding of the utility infrastructure is therefore a pre-requisite for a successful project.

For other technologies discussed above, under SUE, an internationally reputed company GeoSpec has confirmed their willingness to provide these services in India, in a communication with the author.

Conclusions:

Use of various techniques available for detection of underground utilities in a totally non-destructive manner reduces to a great extent the chances of damages during trenchless operations. The information thus obtained can also be used to create maps of a city's utility infrastructure using latest tools of GIS and remote sensing, which can be updated on a regular basis as an when a new installation takes place. This would ensure an updated database for all times to come.

I would welcome suggestions, enquiries on any of the aspects covered under this paper on iggs@mantraonline.com .

Acknowledgment:
I am thankful to Mr Luv Sharma, Cosmic Technologies for his inputs on GIS and remote sensing aspects. I am also thankful to Mr Daran Rehmeyer, PE, CDT, GeoSpec, LLC, for his inputs on various aspects of SUE. I would also like to express my gratitude towards other directors of my company, IGG Services (P) Limited, Mr Abid Hasan and Mr P S Mukherjee for their contributions.