CABLE ROUTE PLANNING AND INSTALLATION CONTROL: RECENT ADVANCES

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Abstract: Recent software advances have improved the efficiency and accuracy of cable route planning and have provided better quality assurance and control during installation – important improvements for both the owner and installer. Geographic information system (GIS) technology has proven to be a reliable means of integrating various data forms into a single platform. Recent developments in 3D GIS provide the capability to deal with very large data sets and convey information more effectively than traditional, 2D static maps. In cable installations, real-time slack management systems have been expanded for tension control of lay operations, typical of power cables and plow operations.

1 CABLE ROUTE PLANNING

The planning, installation and maintenance of submarine cables require the collaborative efforts and close coordination of widely dispersed individuals and information. Between 1999 and 2003, methods used for submarine cable route planning were completely transformed. Paper charts and spreadsheet-based tools were replaced by accurate PC-based software operating in a geographic information system (GIS) environment. All data critical to the design are now stored in databases and are readily retrievable and viewed as layers on a GIS map. This software has become the standard for cable route planning. Typical geo-referenced data sources that are stored and accessed by GIS based planning software include bathymetry, soil types, side-scan images, aerial photographs of landing sites, CAD drawings, marine charts, Route Position Lists (as designed, as laid, and as repaired), cable assemblies, and installation notes. The GIS platform, and subsequent software development, has greatly enhanced collaborative cable planning efforts by providing a common data set, a method of accessing various forms of data, and a method of easily exchanging data among design engineers, minimizing errors and time. With the introduction of GIS planning software, a more complete and automated use of the bathymetric data was achieved. Instead of simply estimating bottom profiles along a selected preliminary route using paper charts to detect the presence of large features and side slopes along the route, the new GIS systems use bathymetric contours (provided by the surveyor from multi-beam soundings) to automatically generate the bottom profile and slope graph along the selected route. As the cable planner makes modifications to the cable route to avoid large slopes and hazardous areas, the GIS planning software computes a new bottom profile and slopes along the entire route. By properly linking the plan view and profile graphs, the cable planner can immediately detect how changes in the cable path affect the bathymetric profile (Figure 1).

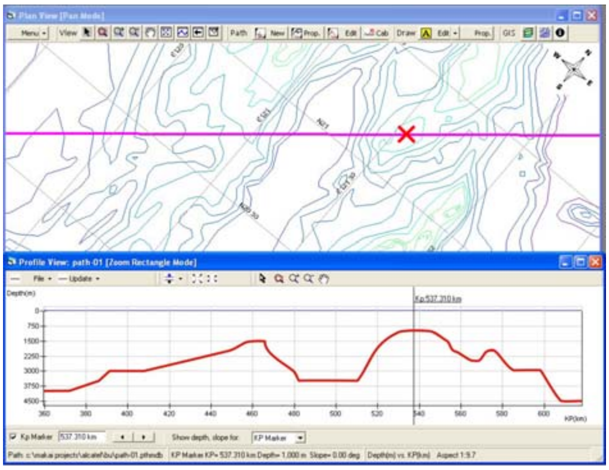

Figure 1. Cable route planners can now link plan and profile views to efficiently manage the cable route design process. Routes are edited using click and drag techniques and precise RPL and cable assembly lists and diagrams are created automatically.

Despite these important advances in cable route planning, which have allowed users to decrease planning time by five to ten-fold, until recently current GIS software could not make optimum use of all the bathymetric data collected by the surveyor. Bottom contours do not always provide the planner with the most accurate representation of the true bottom features and the lateral slopes between adjacent contours.

High resolution bathymetry is particularly important when planning for plow operations and power cable routes. In the last few years, several cases have been reported where plows have been damaged and even lost at-sea as a result of hazardous seafloor features not detected when using bathymetric contour lines to define the cable route. These incidents could have been avoided by making use of the high resolution bathymetric data (i.e. point data collected by the surveyor) during the route planning process. Power cables are particularly vulnerable to suspensions which can shorten the life expectancy of the cable. Contour data do not provide the level of accuracy required to conduct effective suspension analyses. Therefore, new methods of processing bathymetry data are required to generate the highest possible resolution that is needed for these sensitive cable planning operations.

1.1 Processing and incorporating Digital Terrain Data

Bathymetric data are usually provided by surveyors in N-E gridded files that cover the entire surveyed area. The size of the grid cells (dx,dy) in each file depends on the resolution of the data acquired (mainly determined by the footprint of a single echo-sounder beam). For a typical multibeam echo sounder with single acoustic beams of 0.5^o, resolutions of 0.5 meter and 4.5 meters can be expected at echo sounder to seabed distances of 60 m and 500 m, respectively. To decrease the footprint and improve seabed resolution in deep waters, the multibeam echo sounder can be flown closer to the seabed on a tow fish during the data acquisition process.

In order to maintain the accuracy of the data collected by the surveyor, the resolution of the original survey data must be preserved. This can be achieved by creating data blocks (or pages) along the entire surveyed route, in order to minimize variations in water depths (and therefore, footprint size) within each page. Existing software provides automated tools for selecting the appropriate grid size for each block in order to match the smallest footprint of the survey data. The goal is to accurately present the shape of the seabed features detected by the survey, while avoiding the creation of high frequency, non-existent features.

Once the data blocks have been defined, the software automatically redistributes the raw data into a grid formation, using one of the several available gridding methods. After grid creation, shaded relief images (Geotiffs) are automatically generated from the gridded data. Custom controls, such as the shading method, color selection, and light position angles allow users to target areas of concern for evaluation during cable path planning. The generation of all the pages along the surveyed route, including reading the raw data files, generating the gridded data and creating shaded relief images for each page is usually completed in a batch process. Thus, this process does not have to be labor intensive. For a typical survey with 80 million data points, the entire process can take one hour. A sample of a single page generated along a route which includes a shaded relief image created during batch processing and several smaller pages of soil type data are shown in Figure 2.

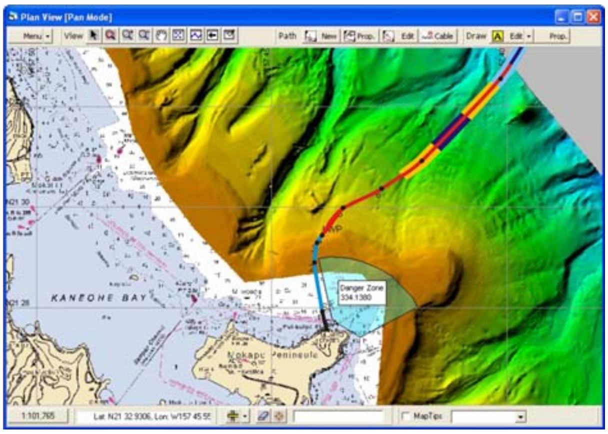

Figure 2. Geotiffs are geo-referenced images which can be inserted into the GIS database enhancing the quality of the information available on any given site.

1.2 Slopes & Suspension Analysis Tools

The use of detailed geo-referenced images to gain a better understanding of seafloor conditions is sometimes sufficient to select a proper route. In other cases, however, further in-depth analysis is required to gain confidence that the hazards to plowing and/or cable suspensions have been revealed and addressed.

Current GIS software includes engineering tools that help the user to identify potential hazards by carefully analyzing seafloor slopes (magnitude and direction) and seabed roughness along the proposed route. As an example, a slope graph can be calculated by superimposing a RPL on gridded bathymetry data so that side slopes and directions can be calculated at any point along the route (Figure 3). Using these tools interactively while designing a cable path, the planner will obtain further confidence in the safety of the selected cable route.

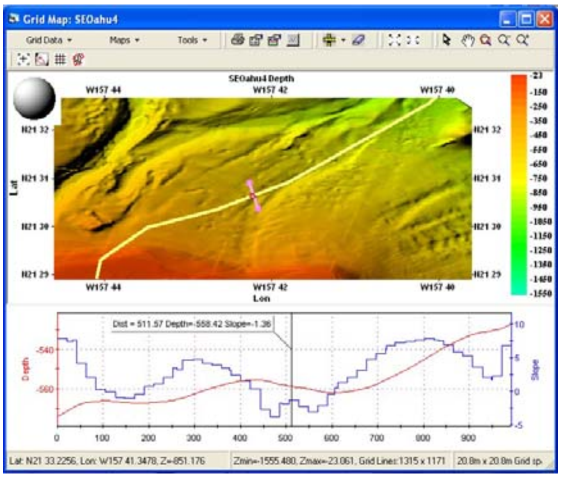

Figure 3. User can interactively create and modify the routes and reference lines, and depth profiles and slope graphs are automatically generated.

In addition to slope, current software applications can provide high resolution depth profiles along the route. This, in turn, allows for the computation of the cable length required to achieve the desired seabed slack with accuracy greater than those computed using the conventional method of intersecting bathymetric contours. Such accurate seabed profiles are also essential to the complete analyses of cable suspensions along the route.

With the growing number of power cables and umbilicals being planned and installed, it has become necessary to incorporate suspension analysis as one of the key elements of route and installation planning. New software tools have been incorporated into GIS planning software that allow users to quickly calculate the location, length of expected spans, and bend radii at cable touchdown points. These tools can provide detailed engineering data, including the shear forces and bending moments, acting on the suspended cable. The additional information necessary to perform these analyses can be readily obtained from the cable manufacturer's data (e.g., wet weight and bending stiffness of the cable). With this knowledge, the user can estimate suspensions for a variety of tension values used during the installation.

These same cable suspension analysis tools are also being used during survey operations associated with the selection of cable and pipeline routes. As the survey takes place, computations of cable suspensions along the pre-selected route can be completed on the "fly", and adjustments to the RPL (and to the survey coverage area) can be completed, considerably reducing the time required to select an appropriate route and leading to lower survey costs.

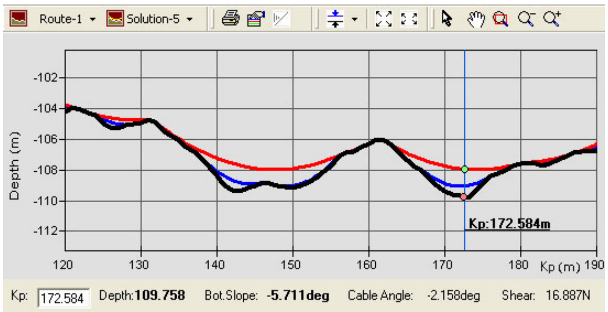

Figure 4. Example of cable suspension analysis for different tensions. This example shows the results of laying a cable over a section of the route (black line) using two different tensions. The final cable shapes are shown in red (for zero tension lay) and blue (for a higher tension lay).

1.3 3D EDITING AND VISUALIZATION TOOLS

With the introduction of Google Earth™ and the rapidly growing number of public databases containing geo-referenced terrain, bathymetry and imagery data (e.g., US Geological Service and the National Oceanographic and Atmospheric Administration), the GIS world is evolving towards a three-dimensional world. While the use of two-dimensional GIS systems have provided great advances in the speed and accuracy with which cable routes can be planned, it is not always easy to visualize and quantify the seabed features and slopes (magnitudes and directions) along and in the vicinity of the cable route.

A 3D GIS planning tool with editing and visualization capabilities can take the route planning process a step further by providing the user with a 3D immersive "virtual reality" environment from which to analyze and re-design the cable path. This is particularly true for shore landings and areas where detailed bathymetry and imagery is available (Figure 5).

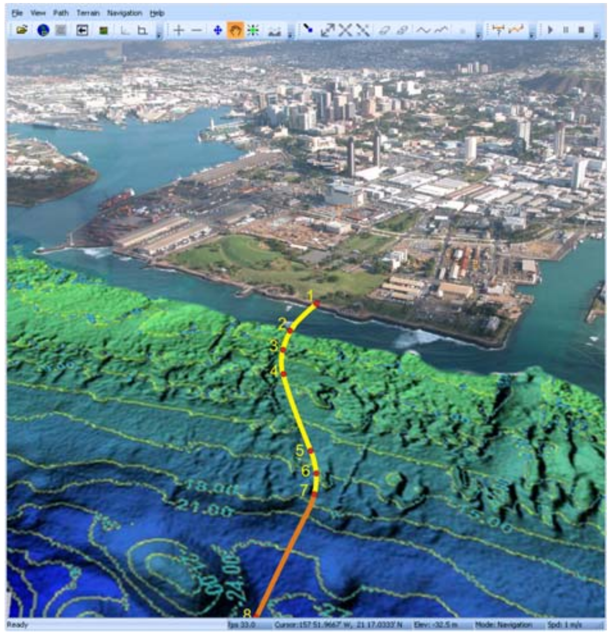

Figure 5. Visualizing and editing a cable route in a 3D, geo-referenced system.

Three-dimensional GIS systems are especially useful in cases where the planner needs to display data that change in space and possibly in time. The US Department of Defense (DoD) cable arrays fall into this category; here the hardware design and its final placement on the seabed directly affect the cable system performance. For example, as the planner designs the cable route and location of the sensors, it is important to show the acoustic coverage of the sensors in the water column. Being able to analyze sensor performance as a function of other variables, such as temperature distribution or density stratification in the water column, during the planning process would be highly beneficial.

For the cable route engineer to make efficient use of the tools mentioned, they should be available in a single software platform. These planning tools already exist, and they are designed to work in conjunction with each other and share information in a common GIS database. When changes are made in one application (e.g., a change to the RPL), the changes are automatically updated in the other applications.

Using a single software platform that contains all the tools required to complete the desired cable path analyses, increases the efficiency of the cable planning process and presents fewer possibilities for critical errors.

2 CABLE INSTALLATION

As the industry converted to GIS based cable planning tools, a similar transformation occurred in the use of real-time cable installation systems to control the cable position and slack on the seabed. These systems have substantially increased the quality of submarine cable installations, and this has been proven in many commercial and military cable installations.

A real-time cable lay controller uses a sophisticated three dimensional dynamic model of the submarine cable to accurately analyze, monitor, and predict cable behavior during installation. Figure 6 illustrates the key parameters that are included in the model. This fast, finite segment, dynamic model includes all the significant factors influencing the position and slack control of the cable. Full 3D modeling, different cable types with in-line bodies and transitions, complex cable shapes that change with time, 2D or 3D bottom terrain and currents that change with depth and time are all included in the program.

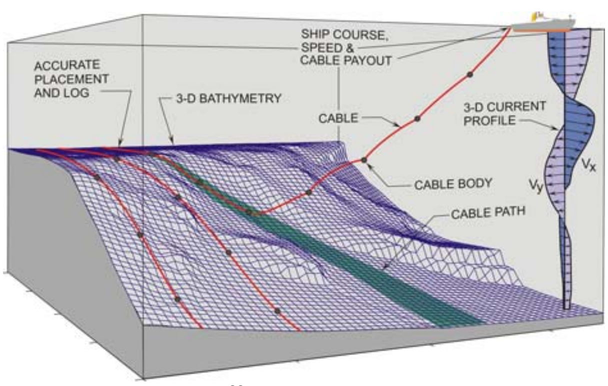

Figure 6. Factors affecting the 3D dynamic shape and touchdown conditions of a real submarine cable lay.

During the last three years, several improvements and expansions of existing cable management systems have occurred. These improvements, which are discussed below focused in the areas of: (1) tension control for lay operations and (2) tools to exchange data to shore in order to improve onshore monitoring of the lay(s) and to receive needed technical support.

2.1 INSTALLING WITH TENSION CONTROL

When laying cable with bottom-tension, the onboard cable engine can be operated in tension control mode instead of speed control mode. In this mode, the cable engine manages cable-payout to maintain a fixed value of cable tension at the cable engine. This mode is especially important during plow operations, when the cable is buried in the seabed, and the installer needs to avoid any excess slack or loops ahead of the plow that can lead to entanglements and damage to the cable.

Conversely, when laying cable with bottom slack, the tension measured at the cable engine is fairly constant and almost independent of the slack value (its value is close to the standing-weight of the cable at the touchdown water-depth). Cable tension at the cable engine does not respond much to cable engine speed-changes until tension on the seabed is developed. Therefore, the cable engine is normally used in speed-mode where its speed is set by the operator based on instructions from the cable management control system in use.

Cable-lay control systems that model the shape of the cable during lay operations often have modes of operation closely matching the modes of control used by the cable engines. When laying cable with bottom tension, the software can use the measured tension as an input instead of the more commonly used cable distances. This ensures that the resulting cable shape more closely matches the reality of the lay operation. This is particularly true in cases where the roto-meter has slight cumulative errors or the true seabed distances are different from those expected based on the survey data. Even though modern roto-meters are accurate, small measurement errors will accumulate over time and may become significant. Example: A roto-measurement error of +/-0.2% accumulates to +/- 173 m error over a 24 hour period when laying cable at 1 m/s. This error is significant when trying to model the cable and its tension level. When the cable is laid with slack, this error produces only a small change in the final as-laid slack value, but it does not affect the calculated touchdown positions.

When the control system uses measured tension at the cable engine as an input, the system estimates the cable-out values in order match the measured tension. Behind the scenes the system monitors the difference between the measured and estimated roto. This difference can then be used to improve the roto-meter calibration over time. By improving the accuracy and correcting the errors of the measured cable distances, the cable-lay control system can be switched between the two modes without affecting the estimated shape of the cable.

The importance of validating the cable model against both measured roto readings and the measured top tension should not be under-estimated; an accurate cable model is a valuable tool during a lay operation. A well calibrated cable-model will allow for accurate placement of Uraduct or other protective measures on the cable at the location of cable or pipeline crossings. It provides a means for managing cable payout ahead of the plow should there be no visual feedback from video-cameras on the plow.

2.2 REMOTE MONITORING

Software tools have been incorporated into existing cable management systems which simplify data exchange between ship and shore, so that onshore personnel can follow the installation and provide technical support if needed.

When added to the existing cable management system, these new tools allow a user to transfer information to shore in near-real-time for reporting or support purposes. The main capabilities of these tools include:

- Transfer starting conditions for the lay and periodic updates from at-sea to shore;
- Allow the on-shore users to log all critical data during a cable lay;
- Allow the on-shore users full access to the data so that they can compute the 3D cable shape in near real-time during a cable lay, thus monitoring the surface and seabed cable conditions and providing technical support when necessary;
- Create detailed reports of any as-laid cable lay data to present to the client as needed.

The system is made up of:

1) An at-sea server version of the software, which collects, encrypts, and compresses all pertinent real-time instrument and model data and transfers it, via the Internet, to another site. Features include the ability to precisely specify which data will be included and the frequency of the updates to minimize bandwidth.

2) The on-shore client version of the software, which retrieves data packets from the Internet and expands, decrypts, and updates the local project so that it contains the latest data available.

Figure 7 shows a simple schematic of a remote software system.

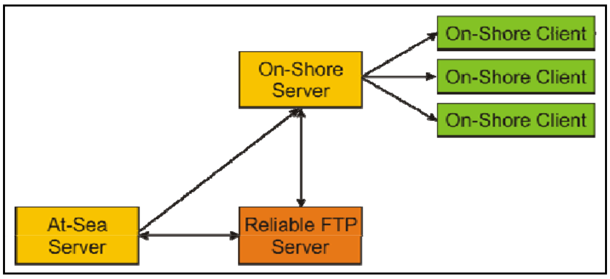

Figure 7. Remote software schematic.

Depending on the availability of a continuous Internet connection or only sporadic transmissions to shore, the program operates differently. If continuous connectivity exists, the on-shore server can receive, in almost real-time, data from the at-sea server (e.g., GPS, cable engine) allowing on-shore personnel to independently run the cable management software and monitor the lay. To lower bandwidth requirements, the user can specify a lower frequency of data transmission (e.g., sensor data transmitted every 10-15 seconds instead of 1 to 2 seconds). Despite using less data, this approach still allows the on-shore user with a complete picture of what is occurring at sea. An even simpler method which requires only periodic updates (primarily used by managers who want to get periodic information from the vessel, but are not interested in computing their own cable solutions or providing technical support), involves sending of specific compressed packages of data to a FTP server. The on-shore server automatically checks the FTP server for updates, downloads the updates and makes the data available for processing.

3 CONCLUSIONS

Software improvements in the submarine cable industry have helped move the planning and installation of submarine cables away from art and more toward science. Powerful tools, such as common GIS databases, allow collaborative development and close coordination between all parties involved in a cable project. Tools specific to the planning provide fast, error-free creation of cable assemblies and route position lists.

New on-going developments in the area of 3D GIS are taking the route planning process into the next generation by providing the user with a 3D immersive “virtual reality” environment from which to analyze and re-design the cable path; this is particularly true for near-shore approaches and landings and areas where detailed bathymetry and imagery are available.

Sophisticated cable control with real-time 3-D cable modeling has been expanded to control tension lay operations (e.g., plowing and power cables). These shipboard control systems also allow at-sea installers to send installation data to managers on-shore in real-time and receive technical support as needed. Quality control managers can now simultaneously monitor multiple lays in progress from shore.