Analyzing Europe's Largest Suspension Bridge

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Key words:

ABSTRACT

Landinspektoerfirmaet (LE34), the largest private surveying company in Denmark (employing between 60 and 70 people), in June conducted a four-day deformation analysis survey of Europe's largest suspension bridge: the eastern portion of the Great Belt Fixed Link. Under contract to the government-owned company A/S Storebaelt, LE34 measured the amount of bridge settlement that occurred during the transit of some 20,000 Danes who walked across the bridge to celebrate the opening of the Great Belt Fixed Link, an inter-island complex consisting of two bridges and an undersea railway tunnel which link the islands of Funen and Zealand. The project discussed here demonstrates the feasibility of using GPS to measure the full dynamic range of an engineered structure's response to loading over time in a timely and cost-effective manner.

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1. INTRODUCTION

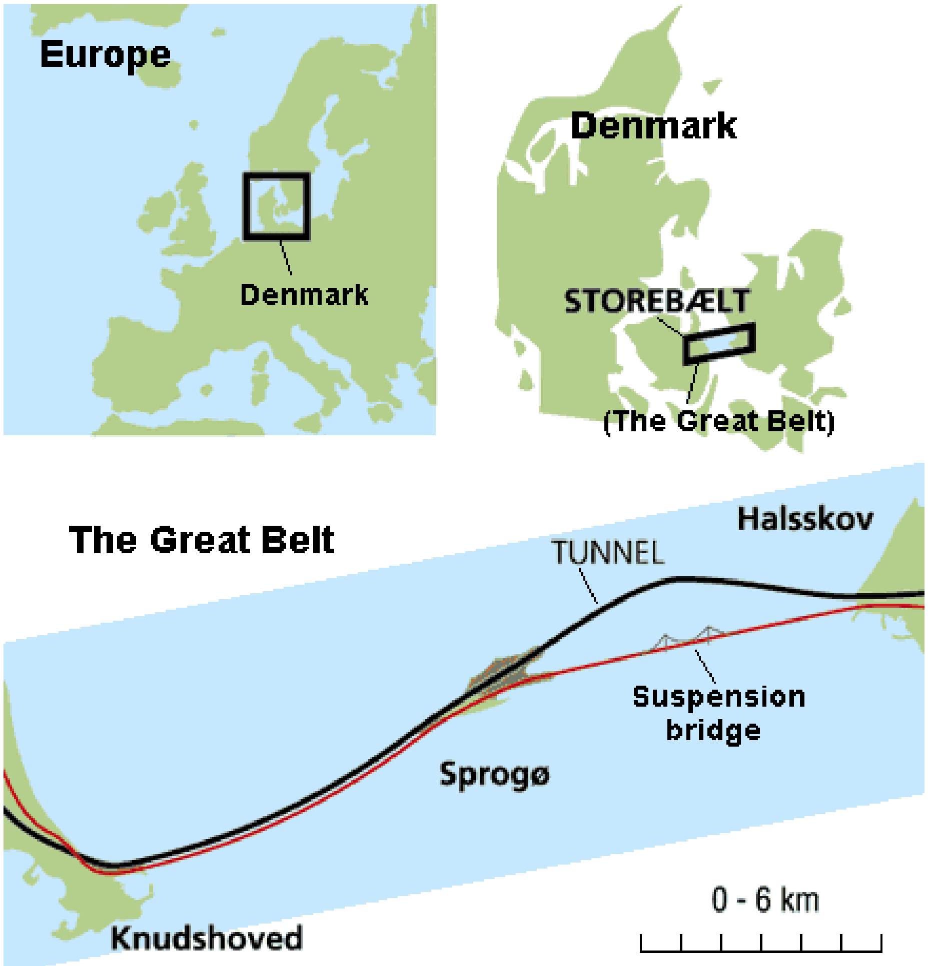
Continuously monitoring the integrity of bridges, dams and other large-scale structures can provide valuable information concerning public safety aspects of civil, structural and earthquake engineering. Continuous monitoring systems must be able to record precise deflection data as closely as possible to real-time often on a continuous, around-the-clock basis. Traditional land-surveying techniques which rely on the presence of surveyors to gather data thus demand manpower which is often infeasible. GPS receivers and robust telemetry, on the other hand, continuously record data from GPS satellites and require little, if any, intervention on the part of the surveyor. LE34 used GPS-based tools to conduct a real-time deformation analysis of Denmark's newest suspension bridge while 20,000 pedestrians crossed it to celebrate its opening last June. In other monitoring sessions, traditional survey methods where also used for comparison and overdetermination purposes. Results indicated good agreement between the two, although the GPS survey was more accurate over long distances.

2. PUBLIC RELATIONS EVENT

The deformation analysis was part of an elaborate four-day public relations event conducted by the Danish government to celebrate the opening of the Great Belt Fixed Link. To illustrate the safety and integrity of the suspension bridge, LE34 measured the amount of deformation while 20,000 Danish citizens marched across it.

3. THE GREAT BELT FIXED LINK

The Great Belt is a narrow straight of water separating Funen and Zealand, the largest of more than 400 islands comprising Denmark. The Great Belt Fixed Link is an inter-island complex consisting of two bridges and an undersea railway tunnel linking Funen and Zealand. In the middle of the Great Belt (thus between the two large islands) lies the tiny island of Sprogoe which effectively divides the waterway into an eastern channel (between Zealand and Sprogoe) and a western channel (between Funen and Sprogoe). The sus-pension bridge is that portion of the Great Belt that crosses the eastern channel above the sea. Under the sea, a railway tunnel also crosses the eastern channel. To the west, a bridge for both rail and motorcar completes the Great Belt Fixed Link.



Map over Europe – Denmark – and The Great Belt.

4. THE SUSPENSION BRIDGE

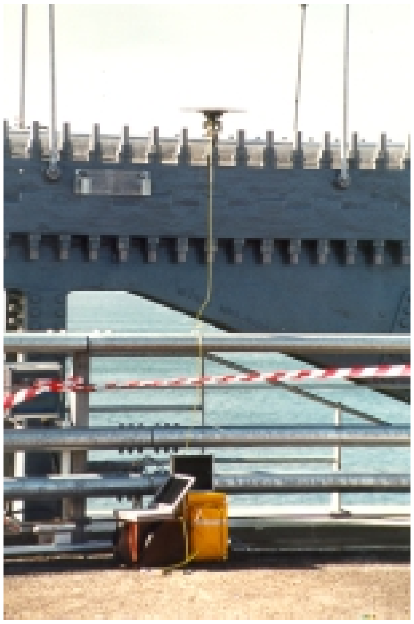
Completed in 1998, the eastern portion of the Great Belt Fixed Link is the largest suspension bridge in Europe and the second largest in the world. The main span measures 5,328 feet (1,624-meters) and extends the motorway from the western channel linking Sprogoe and Funen across the eastern channel linking Sprogoe and Zealand. The suspension bridge substructure consists of two pylons, two anchor blocks, 19 bridge piers and two abutments. It contains 259,000 cubic meters of concrete and 44,000 tons of reinforcement steel. The superstructure consists of two main cables supporting the suspension bridge spans. Each cable measures 827 milli-meters in diameter and 3 kilometers in length.

The Bridge for the eastern portion of the Great Belt Fixed Link

5. GPS EQUIPMENT VERSUS TRADITIONAL EQUIPMENT

Europe's largest suspension bridge posed a classic problem for LE34 surveyors. They did not have the opportunity to choose between traditional equipment and GPS equipment. As the adequate number of GPS antennas were available (6) the surveyors chose GPS. Placing traditional equipment upon the pylons could probably produce the same results, but the lack of appropriate number of servo-equipment did not made this option possible.

To obtain GPS-based measurements, LE34 used four GPS Total Station® 4000 and two GPS Total Station® 4800 systems to conduct static measurements of the central node and pylon movement in real time as 20,000 Danes crossed the bridge during each of four days. The company computed the survey every 15 minutes, taking four sets of coordinates per hour. Each GPS Total Station included a dual-frequency receiver, GPS antenna, data radio, power supply and cables. Surveyors located two GPS stations on shore (one at each end of the bridge), one on each of two pylons and two on the central node in the center of the bridge. At the end of each day, LE34 brought a portable computer directly to each GPS station where surveyors downloaded the deflection data directly.



The 4000 receiver mounted on the bridge

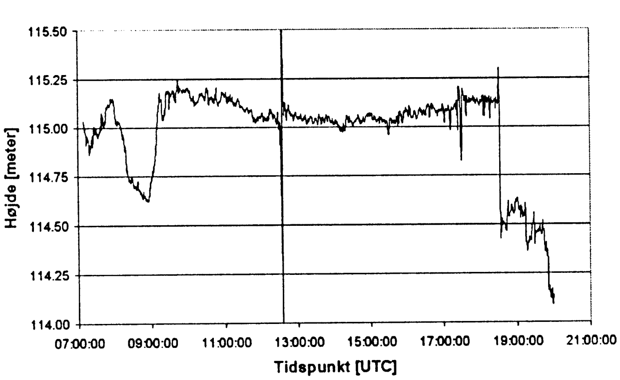
The bridge on a pylon

6. DATA

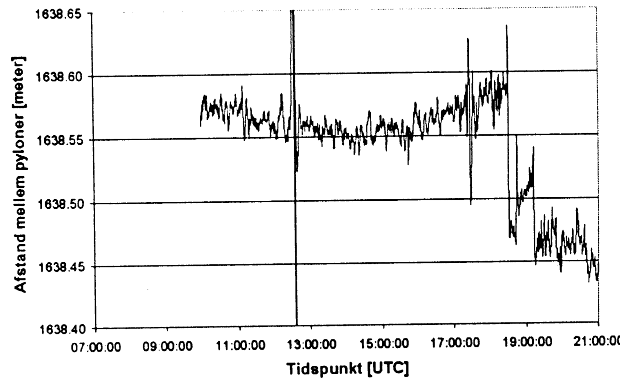
Data files from all six Trimble GPS Total Stations were processed June 4 through June 7, 1998. Each of the six stations employed a Trimble GPS receiver and GPS antenna for the duration of the project. Daily data were recorded at 15-second sampling intervals but processed at 900-second epochs. While all stations recorded data from satellites higher than 15 degrees above the antenna's horizon, solutions were generated using data above 15 degrees elevation.

7. ANALYSIS METHODS

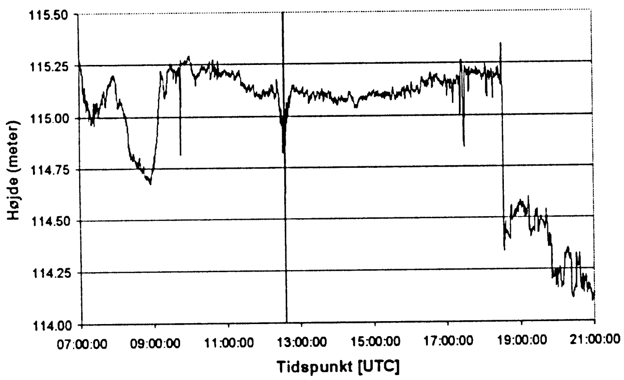
LE34 processed the data using Trimble's GPSurvey software, and performed the adjustment of vectors using TrimNet. This special project did not require transformation from the WGS84 system to a local datum, as is typically required for other projects but the analysis was carried out on the basis of the processed and adjusted WGS84 coordinates.



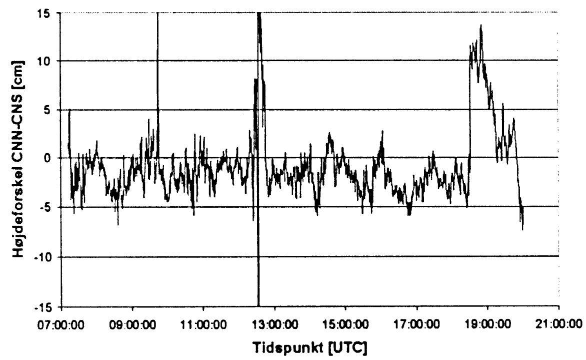
Monitored height CNN



Monitored distance between the pylons



Monitored height CNS



Rotation of central section

8. EVENTS

8:00-9:00
The Danish Prince Frederik opens the bridge and at this time the bridge is open to the public. The deformation of CN (north and south) is apx. 0.5 m.
9:00-
The public is spreading all over the bridge, and deformation decreases to apx. 0.3 m.
9:42-9:47
There is some corruption of the signal or bad satellite constellation.
15:00-
The public is returning to the center of the bridge having had there lunch on Sprogoe.
17:28-17:30
The bridge closes to the public and a heavy vehicles are entering the bridge resulting in sudden movement of the GPS antenna.
18:32
The heavy vehicles stay on the bridge to finish the installation of wind protection.

9. SUMMARY OF THE RESULTS OF THE LOAD DEFORMATION SURVEY.

Load increase and decrease occurred as pedestrians walked across the bridge 3-5 hours each day. GPS receivers continuously monitored the load change, gathering data for different periods of time each day: 4 June-7 hours; 5 June-12 hours; 6 June- 11 hours; and 7 June-9 hours. The passage of large trucks occasionally disturbed the measurements and prevented the surveyors from calculating load change. However, the trucks remained in position long enough for the surveyor to calculate the amount of deformation created by their passage. Deformation was surveyed at the central node and pylon tops. Results indicated 0.5 meters vertical deformation with pedestrians upon the bridge, and 1.2 meters when the trucks suddenly passed. Results also showed a maximum transversal rotation of 0.08 m when pedestrians were on the bridge, and 0.16 meters when the truck arrived. Results indicated a maximum sum of 0.18 meters deformation of the pylon tops toward the central node.

10. CONCLUSIONS

LE34 obtained accurate results with the GPS-based survey. The company also achieved results fast and cheap with the GPS-based survey. GPS-based results probably cost half as much as traditional methods, primarily by reducing man-power. Traditional surveying techniques required LE34 to employ a full-time surveyor during each of four-day marathons during which the company gathered data. In the GPS-based survey, surveyors set up the receivers and left for the day, returning after 10 PM to download the data. The project demonstrates the ability to measure accurately the full dynamic range of an engineered structure's response to loading over time faster and more cost effectively than traditional surveying methods.