DEFORMATION MEASUREMENT ON BRIDGE AND TUNNEL OF THE FIXED LINK BETWEEN SWEDEN AND DENMARK

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Abstract

Deformation surveys are carried out as part of the maintenance of larger highway bridges in Denmark, in order to evaluate long-term deformation and settling. The Danish Road Directorate, in cooperation with the Swedish Vägverket Consult have carried out an initial survey for the entire connection for Øresundsbro Konsortiet, the owner of the fixed Link between Sweden and Denmark. Only some of these surveys are described in this paper.

1. Introduction

The link across Øresund, connecting Copenhagen in Denmark with Malmö in Sweden, is 16 km. in all. The connection consists of a submerged tunnel from the Danish coast, with an artificial island in the middle of the Sound via a 8 km long bridge, with a cable-stayed suspension bridge in the middle, to the Swedish coast. The link is comprised of both a railroad and a motorway.

The link was opened July 1, 2000.

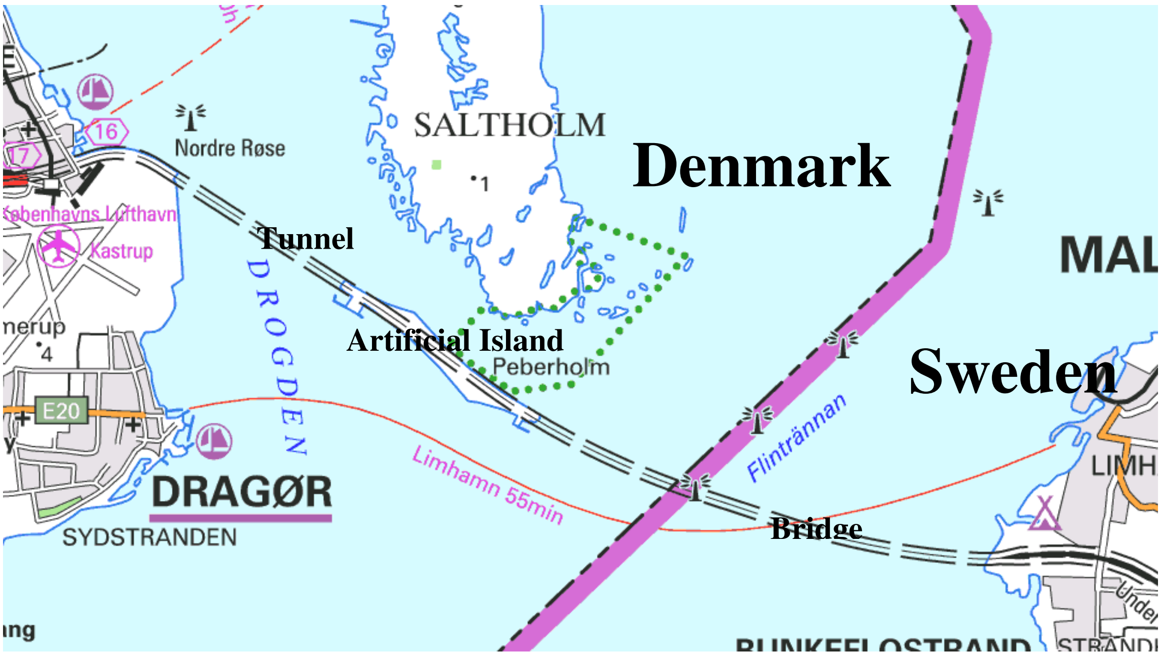

Figure no. 1 Overwiev

Figure No 2. The bridge seen from Sweden

2. Basic surveys

The first step in deformation surveying of a construction is to carry out a basic survey, consisting of individual surveys inside a narrow time frame (e.g. 1 month). All following surveys will be compared to the results of this survey. It is therefore important that this survey is carried out before the deformations to be observed can be expected to occur.

It is also important that the basic survey is carried out with a high degree of reliability regarding results, as it is obviously impossible to follow up with check-surveys after deformations have taken place or can be expected to have taken place.

Danish bridges are never founded on bedrock, but are typically founded on limestone, clay, or sand, and there is a fundamental need to ascertain any settling or movement of the substructure. In addition, there is the need to be able to evaluate deflection and deformation of the superstructure.

A decision is made as to which types of deformation are to be determined for each area defined. This can be horizontal and vertical movement, rotation on vertical and longitudinal axis, deformation, expansion/contraction, deflection, torsion.

For the link it was decided to do geometric levellings in the tunnel and on the artificial Island (Peberholm) ans well as on the bridge deck. It was decided to do trigonometric levellings on the pillar tops.

3. Heights

One of the first tasks to be carried out in connection with basic surveying for future deformation surveys was a check on the main heights system (Fig.3). This survey was done by KMS* together with LMV**. As well as connecting the surveys of the individual parts of the link, this levelling will be used to connect the heights systems in the Scandinavian countries.

LMV og KMS have each carried out 3 independent precision double levellings between known points on the Swedish and Danish sides, respectively. These levellings were carried out with Zeiss NI002, with compensators and invar rods. The m.s.e. for this levelling was estimated at 0.3 mm/√km.

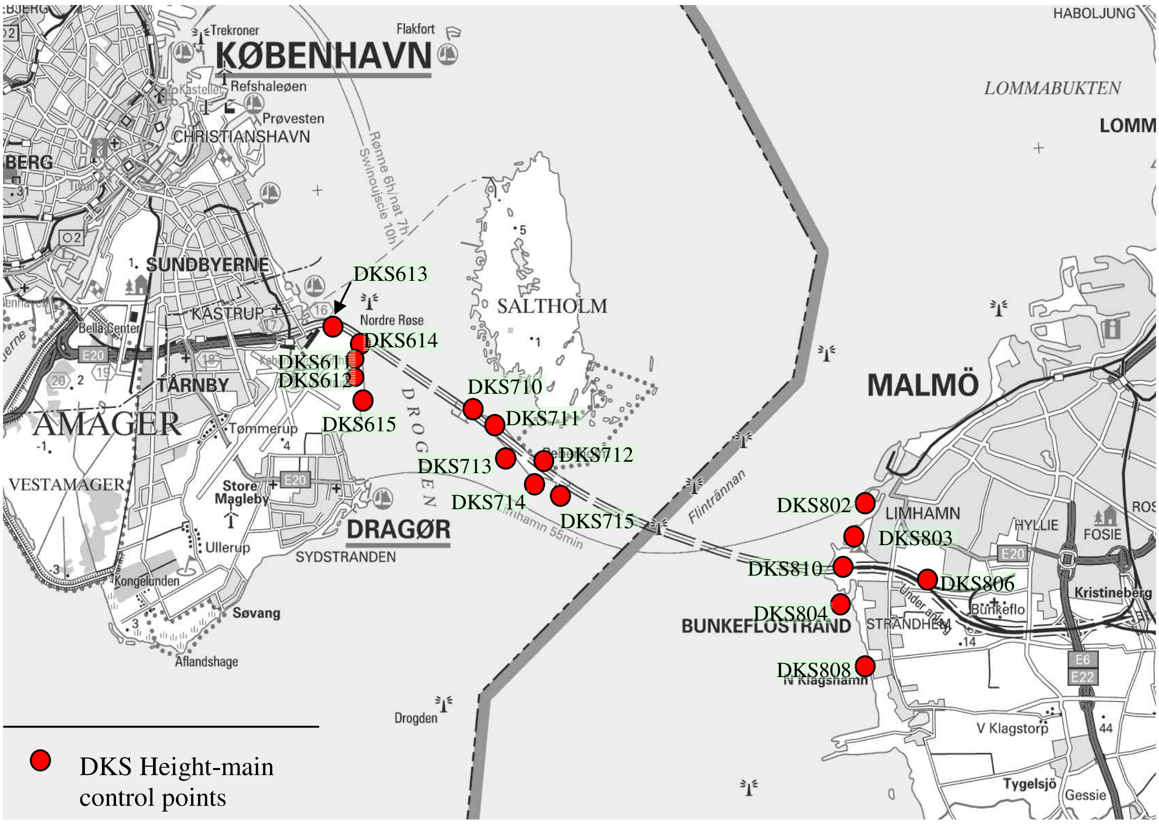

Figure No. 3. *Overview of points in the main heights system.*

4. Tunnel

The contractor had already established and controlled a long series of points located in the northern rail tunnel and the northern road tunnel between the Danish coast and Peberholm (the artificial island). The surveys were carried out as levellings to adapters mounted on inserts (an insert is a cylinder with internal thread), which are cemented to New Jersey Barrier as well as the concrete wall.

Figure No. 4 *Control point in Tunnel Insert with adapter mounted.*

Figure No. 5 *Levelling in Tunnel using invar-rod.*

The purpose of the surveys in the tunnel is first and foremost to disclose the relative dimensions of settlings between the indivdual tunnel elements and the dimensions of deformations in the individual elements.

The Road Directorate has carried out double levelling throughout the entire tunnel in the northern road tunnel and the northern railway tunnel.
All levellings are carried out as double levellings, using Leica Na3000 digital levelling instruments.

The accuracy was estimated in advance to be 0.8 mm/√km. The actual m.s.e from the final adjustments turned out to be 1.71.

5. Trigonometric levelling at piershaft tops

The purpose of the trigonometric levelling at the pillar tops was to make it possible to check the individual elements in the substructure for deformation, both longitudinally and vertically (settling) and for rotation, both on vertical and horizontal axes (unsymmetrical settling).
A combined level survey and trigonometric levelling of control points with tachometer on top of each pier shaft has been done on the whole bridge.

An insert with 10mm internal thread, into which an adapter can be screwed to act as prism carrier, has been bored into and cemented to every control point (see Figure No. 7).

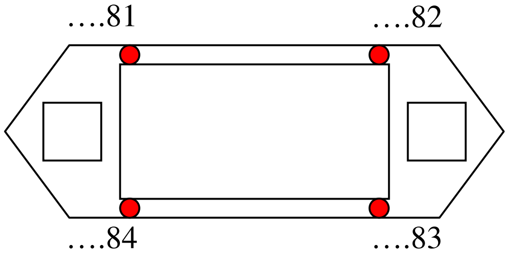

Figure No. 6 *Placing of points on top of pier shaft.*

5.1 Carrying out the survey

The surveys are carried out by Vägverket Consult and the Road Directorate, and both groups have used free stations for the trigonometric levelling.
Both groups have used Leica TCA2003 tachometers.

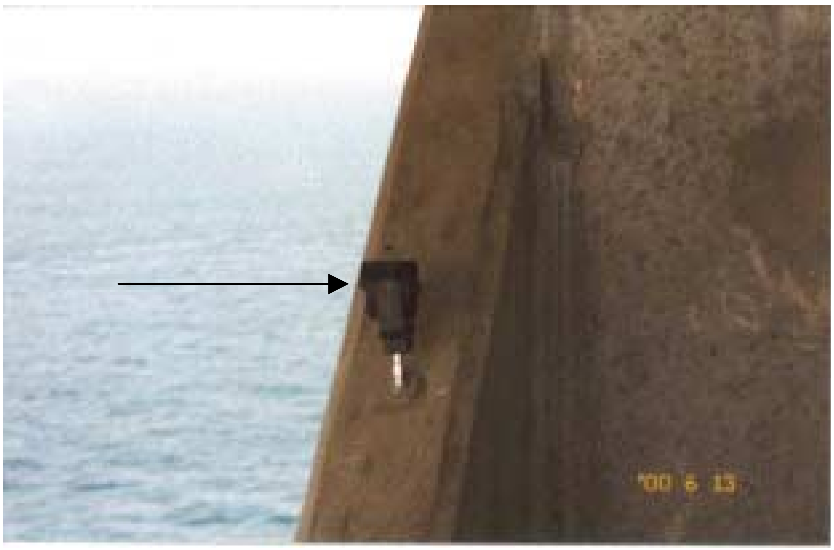

Figure No. 7 *Prism mounted in control point on pier shaft.*

Four whole rounds have been surveyed at each station. The survey principles can be seen in Fig. 8; thus only the points xx82 and xx84 are measured redundant (see Fig. 6), the two remaining points are surveyed to get the position and to determine the distance between them in connection with calculation of pier deflection based on the geometric precision levelling (see section 6 below).

In connection with the surveys, it soon appeared that the individual pier shafts were not completely stable in the bridge's longitudinal direction; the distance between two pier shafts could vary with up to 10mm in the course of a day. The calculations do not take these variations into consideration, in that they only appear in the calculations as adjustments of the distance between two piers. The variations should be viewed as a consequence of bearing friction, and the fact that the piers are relatively narrow in relation to height.

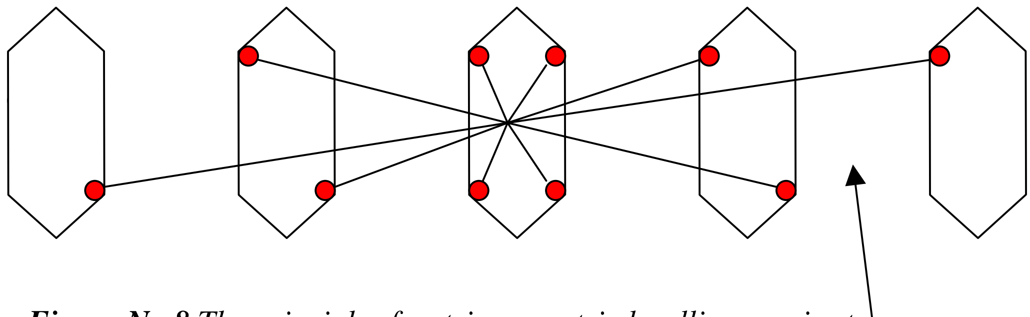

Figure No 8 *The principles for trigonometric levelling on pier tops.*

5.2 The calculation process

All stations are adjusted as a free-net so that any tensions from the fixed coordinates can be avoided. Two fixed points in the stone revetment at each abutment have been surveyed using GPS. These points are included in the trigonometric levelling, and can therefore be used in a following transformation.

It was decided to use this procedure with a free-net adjustment and a following transformation since even slight errors in the fixed coordinates, of, for instance, 2-3 mm, would result in greater coordinate „error" around the pylons.

The control points on the pillar tops are determined relatively, with a point-m.s.e. of 2-3 mm relative to the control points on neighbouring piers.

In connection with future surveys, one would naturally find larger absolute coordinate differences, especially on piers lying a distance from the fixed points on the coasts.

In order to make optimal use of these surveys, we should therefore concentrate on relative deviation between neighbouring piers.

By, for example, using the coordinates on piers 3 and 5 as fixed coordinates, it is possible to calculate deformation for pier 4. To facilitate the calculation process, a complete net calculation has been done, giving an absolute m.s.e. in relation to the main points of up to several centimeters, but the m.s.e. relative between neighbouring piers is estimated to be 1-3 mm.

5.3 Comparison of Vägverket's and the Road Directorate's surveys.

An extract from a comparison of Vägverket's and the Road Directorate's surveys is seen below. There are horisontal differences going up to several cm. as coordinates closer to the center of the bridge are compared, but as described above, this is only an expression of the impossibility of comparing two independent surveys directly. It is, however, possible to compare a series (e.g. 3-5 piers) in two different surveys, with a transformation over the outermost piers in the series, to determine whether there are deformations of the middle pier(s) in the series being compared..

Pier E20	Danish Team			Swedish Team			Differences			Average		
	E	N	Z	E	N	Z				E	N	Z
432081	5557.640	3716.839	23.774	5557.636	3716.832	23.776	0.004	0.007	-0.002	5557.638	3716.836	23.775
432082	5550.623	3715.523	23.775	5550.620	3715.516	23.776	0.003	0.007	-0.001	5550.622	3715.520	23.776
432083	5551.511	3710.755	23.770	5551.508	3710.750	23.771	0.003	0.005	-0.001	5551.510	3710.753	23.770
432084	5558.544	3712.086	23.774	5558.539	3712.079	23.774	0.005	0.007	0.000	5558.542	3712.083	23.774
Pier E21												
432181	5532.376	3855.827	22.002	5532.373	3855.822	22.003	0.003	0.005	-0.001	5532.375	3855.825	22.002
432182	5525.379	3854.590	22.024	5525.376	3854.585	22.025	0.003	0.005	-0.001	5525.378	3854.588	22.024
432183	5526.224	3849.824	22.014	5526.221	3849.819	22.016	0.003	0.005	-0.002	5526.223	3849.822	22.015
432184	5533.226	3851.060	22.015	5533.222	3851.055	22.016	0.004	0.005	-0.001	5533.224	3851.058	22.015

Figure No 9. Comparison between 1st and 2nd Measurement.

6. Levelling at top of piershafts

In order to check the elements in the substructure for rotation on vertical axes (differential settling), geometric precision levelling has been done on each individual piershaft between 4 control points.
The same inserts mentioned in section 5.1 have been used as control points (see Fig. 6 and Fig. 7), but without the use of prism adapters.

6.1 Carrying out the survey

Levellings done by Vägverket Consult have been done with Zeiss DiNi12 and Leica NA3000 digital instruments, using 1m invar rods.

Levellings done by the Road Directorate have been done with Leica NA3000 digital instruments, using 1m invar rods.

Control points heights have been determined with a relative point- m.s.e on each pier shaft of 0.2-0.3 mm.

In connection with the surveys, it was intended to log data from the bridge's electronic controle system, which would be capable of providing information on the individual piers' inclination at a specific point in time. Unfortunately, it turned out to be impossible to log data during the period in which the surveys were done.

6.2 The calculation process

Calculations for each pier have been done with the north-eastern point fixed at 1,000 m. This has been chosen because the survey is used for an isolated control of internal inclinations in individual pier shafts.

6.3 A comparison of Vägverket's and the Road Directorate's entire results.

Below is shown an example of a comparison between Vägverket's and the Road Directorate's surveys, showing only quite small deviations going up to 1mm. The deviations are probably caused by the movement of the piers previously mentioned. It is therefore natural to average the two surveys for comparison with future surveys.

Pier E10	Swedish Team	Danish team	Diff	Average	
431081	1.0000	1.0000	0.0000	1.0000	Local Level
431082	1.0129	1.0128	0.0000	1.0128	Local Level
431083	1.0065	1.0070	-0.0005	1.0068	Local Level
431084	1.0168	1.0173	-0.0005	1.0171	Local Level
Pier E11					
431181	1.0000	1.0000	0.0000	1.0000	Local Level
431182	0.9966	0.9966	0.0000	0.9966	Local Level
431183	0.9939	0.9944	-0.0005	0.9942	Local Level
431184	0.9830	0.9834	-0.0004	0.9832	Local Level

Figure No 10 Comparison levelling at top of pier shafts

7. Conclusion

In addition to the surveys mentioned above, an electronic controle system, which is normally to warn of any inappropriate unsymmetrical settling / deformation of pier tops, etc., has also been established on the bridge.

In connection with the basic surveys the plan was for this system to be linked together with the traditional surveys of the bridge. Unfortunately it was not possible to have the electronic system operational during the period when it was possible to carry out the geometric survey.

References

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Danish Road Directorate, 1992: "Notat om bevægelsesmåling af større broer"
(Note on deformation surveys of large bridges)
Danish Road Directorate, 1992: "Generelle retningslinier for måleprogrammer for større broer"
(Guidelines for survey programs for large bridges)

KMS*) The Danish government authority responsible for mapping, charting, geodata, cadastral registrations and the authorisation of licensed surveyors.
LMV**) The Swedish government authority responsible for mapping, charting, geodata and cadastral registrations.