LEVELLING OVER THE ÖRESUND BRIDGE AT THE MILLIMETRE LEVEL

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Key words: Height connection, levelling techniques (ML), Large bridge, high accuracy (mm)

Abstract

In this paper we will present the different height connections between the Swedish 1st order Height Network and its similar in Denmark using different height determination techniques and especially the latest from year 2000 with Motorised Levelling techniques over the new constructed "Öresund" bridge.
Firstly we describe the bridge (more than 8,5 km) and its environment, thereafter the height determination techniques used to perform the levelling and finally we present the results obtained under various and difficult (wind and cold) environmental conditions. The work was done in April 2000 as a Nordic Joint Project by two levelling teams, one from each country Denmark and Sweden under the leadership of J-M Becker.
The result on the millimetre level confirms the high efficiency and quality given by the Motorised Technologies in projects where other techniques never could compete. The presentation includes also some pictures illustrating the whole work.

Zusammenfassung:

Dieser Vortrag beschreibt die verschiedenen Höhenverbindungen zwischen Dänmark und Schweden und speziellt die neuesten Höhenmessungen die über der Öresund Brücke im April Jahr 2000 durchgeführt wurden. Wir werden erstens eine Beschreibung der Brücke (>8,5 km) und deren Umgebung geben, danach die ausgenutzten Nivellements Techniken und letztens von den erreichten Ergebnisse und Messverhältnisse erzählen. Das Projekt wurde als ein Joint Venture Projekt mit einer Manschaft beider Länder Denmark und Schweden durchgeführt unter der Leitung J-M Becker.
Die Resultaten mit Millimeter Genauigkeit zeigen das die Motorizierte Höhenbestimmungstekniken hoch effizient sind und hohe Kvalitet ermöglichen an Stellen wo andere Nivellements Verfahren nicht anwendbar sind. Das ganze wird auch mit farbreichen Bilder illustriert.

Résumé:

Dans le rapport qui suit nous presentons les diverses mesures faites pour raccorder les réseaux altimétriques du Danmark et de la Suède et spécialement le dernier en date effectué l'an 2000 en utilisant le nouveau pont d'Öresund. Nous faisons d'abord une description rapide du pont lui-même (plus de 8,5 km) et de ses abords, ensuite une présentation des techniques de mesures utilisées et finalement les résultats achevés sous des conditions de travail extrêmes.

Les résultats obtenus sont d'une précision millimétrique et démontrent que les techniques du nivellement motorisé sont très efficaces et d'une grande précision la où d'autres techniques de nivellement sont inefficaces. Une série d'images en couleur illustre les travaux de ce projet.

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1. Historical background.

The first levelling connection between the Danish and Swedish height systems was established 1896 and 1898 at Helsingör – Helsingborg. The measurements were done by simultaneous reciprocal observations of special targets set up on each side of the Sound at a distance of about 5 km.
A new connection was done 1939 using *hydrostatic levelling* technique with a submerged water-filled tube for transfer of heights by means of the free surfaces at the ends of the tube.
The difference in results of 17 mm was considered as not so good.

In 1979 the Nordic Height Determination Group decided to repeat the optical levelling connection between Helsingör (DK) – Helsingborg (S) at the same place and with the same technology as under last century. The reasons were several: firstly to detect eventual conti n from Swe Réseau Euro The s agree with logical move nena in Scan is very smal

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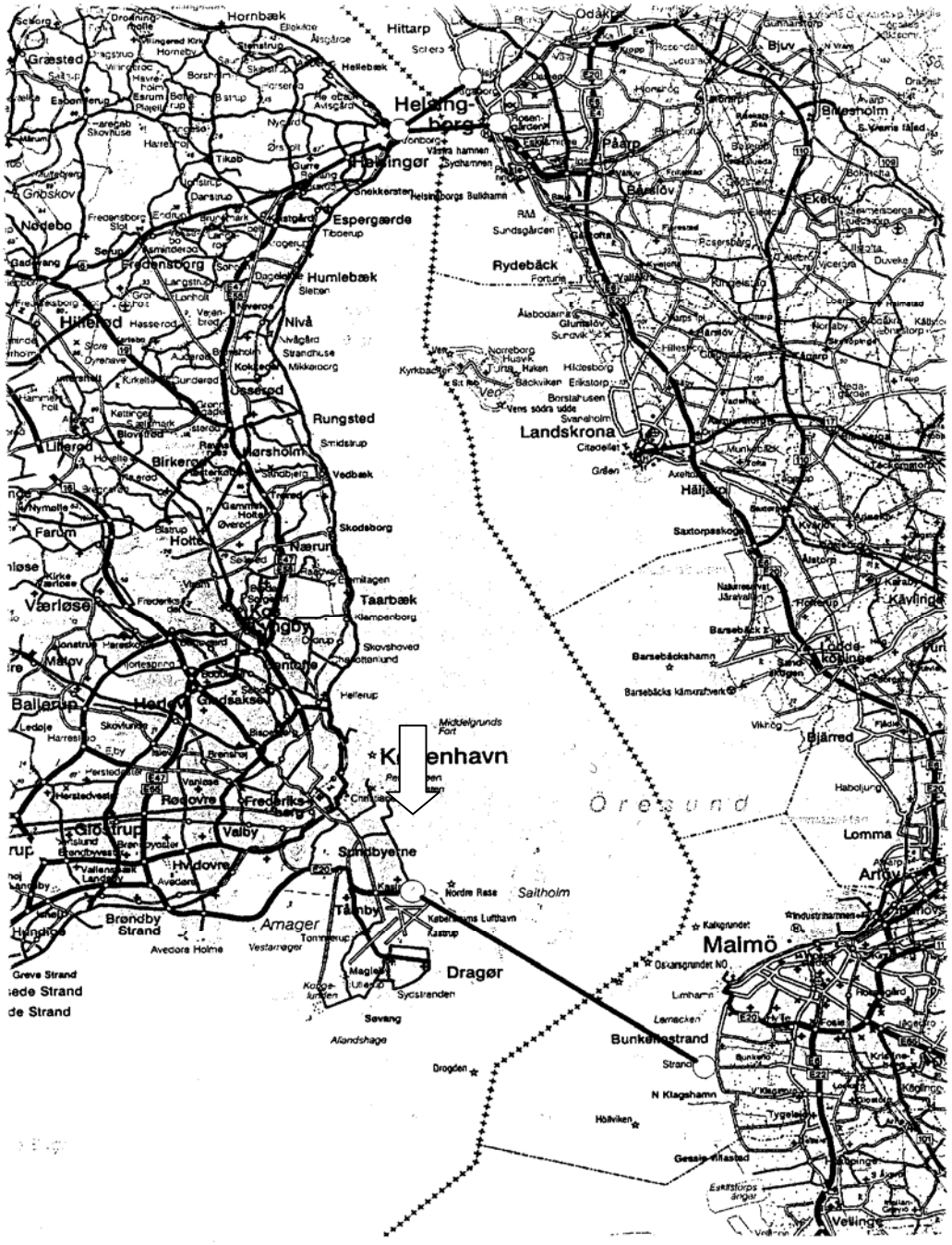

FIG
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On the following map the different measurements are illustrated. In the North part the Helsingör – Helsingborg connection and in the South part the Öresund connection from Malmö (S) to Copenhagen (DK) from June 2000

2. The Öresund Bridge and Link.

2.1 The road-rail link:

The Öresund combined road-rail link is composed of several different parts including one tunnel, one artificial island and several bridges with a total length of around 16-km.

2.2 The Bridge is composed of three different bridge constructions as follow:

Western and Eastern Approach bridges connected each on one side of the High Bridge and on the Island or land. The Eastern Approach Bridge is formed with 27 spans (24-à 140-m long and 4-à 120 m) and 3739m long. The Western is only 3014 m comprising 18 spans à 140m and 4 à 120m. In total 51 bridge-piers support the approach bridge spans.

The High bridge with the islands Saltholm and Peberholm in the background.

2.3 The High Bridge is the longest cable-stayed bridge in the world for both road and railway traffic. She is supported by four pylons (each 205 m high), each pair standing on a common caisson. The span is suspended by 80 cable pairs, which are attached to the pylon and legs at regular interval (12m). The High Bridge is 1092m long, with a main span of 490m and a navigation clearance of 55m. The bridge two-level structure is fabricated from steel and

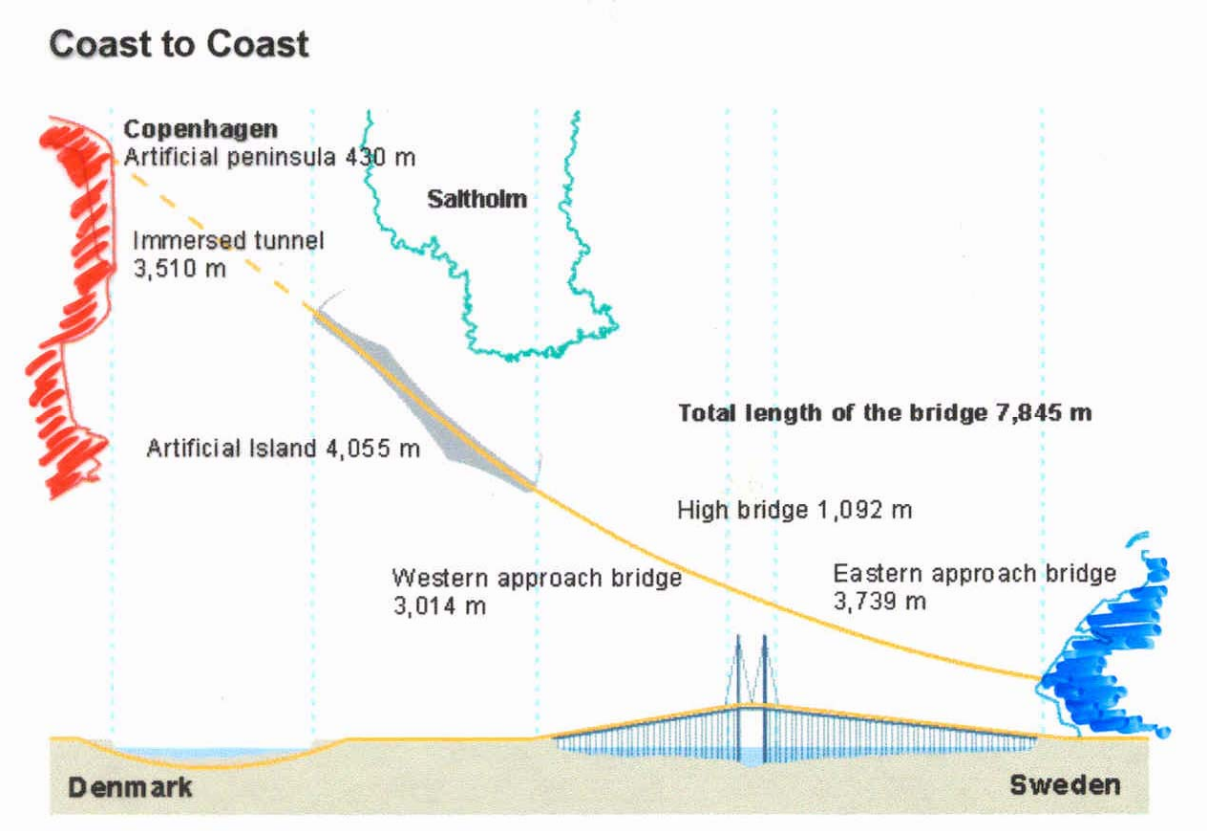
concrete. The steel girder supports the upper deck, which accommodates the motorway, and the lower deck where the railway is located

2.4 The Artificial Island "Peberholm"

The artificial island has been built south from the existing island "Saltholm" with about 9 million m^3 of stone, sand and dredged material to a length of 4 km.

2.5 The Tunnel

The tunnel is the world longest immersed tube (4 tubes side by side) tunnel (4 km) for both road and rail traffic connecting the artificial island Peberholm and the peninsula in Kastrup. The Tunnel is connected to the Approach Bridge by a 560m long viaduct



3. The height connections over the bridge

The height connection between Denmark and Sweden over the Öresund Link demands also some connections to the existing precise levelling lines along the coast in both countries. These land connections to stable benchmarks represent a supplement of some km levelling. The total length to level in our project is about 22 km.

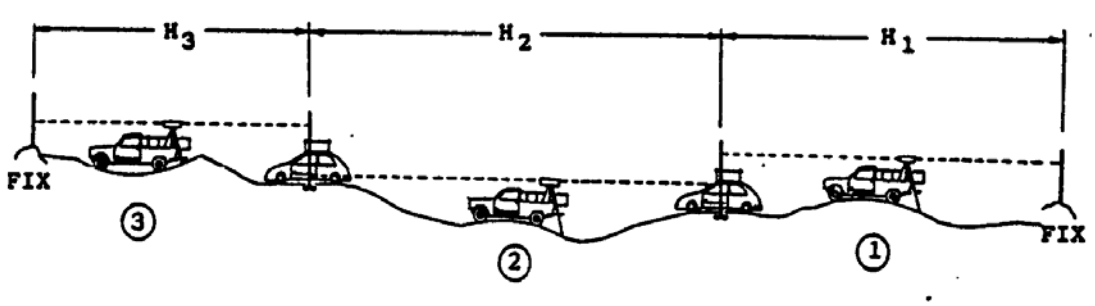
3.1 Benchmarks and Reference points

The Road and Öresund Bridge Company had placed benchmarks along the total link at predetermined intervals and of different types. As example in the tunnel the BM was of removable screw type. At Peberholm screw bolts in foundation were used placed each 500m. On both Approach Bridges the used screw bolts over the span-pillars at intervals of 280 m.
The most unstable and complicated part to level was the High Bridge. Each side east and west from the pylons include several pillars up to 300 m and the main span was 490 m.
Benchmarks were placed in the pylons. Before all operations each BM was given a specific identification number and signalised with colour.

3.2 Different height determination solutions FL, ML, MTL

To level across Öresund using the Öresund Link is an important project of more than 15 km. The different parts composing this levelling line (tunnel, artificial island, bridges, etc) represent different kind of stability for the benchmarks located there. The bridges alone are more than 8 km and composed of more than 50 segments supported by pillars. The constructions of pillars and pylons in armed concrete are very sensitive for the existing meteorological factors and especially for temperature variations during the day and from day to day. The same deformations in height affect the steel main span of the High Bridge. Out over this we have important wind variations most of the time. Other factors giving troubles are the different construction activities (with engines, trucks, hammer, and railway creating vibrations) along the whole link. To achieve high precise levelling under this conditions demand special precautions and it is fundamental that each day measurements start and stop on fasten stable benchmarks. Furthermore it is important that each day start with some check of stability of the starting BM by relevelling the last section from the past day.
Analysing the existing levelling techniques FL (Levelling by Foots), ML (Motorised Levelling) and MTL (Motorised Trigonometric Levelling) we very quickly understand that to do it by classical FL was technically nearly impossible and that for different raisons.

The Motorised Levelling technique (ML) is composed of one instrumental car and two staff cars working as shown in the figure below. The technical details are published in many technical papers in the references.



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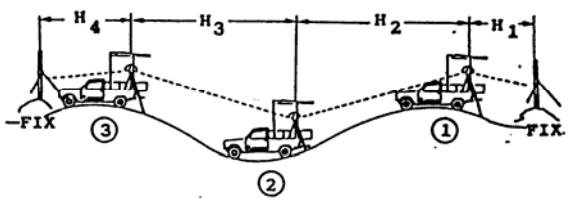

The Motorised Trigonometric Levelling technique (MTL) using tree identical instrument cars operating as in the figure above. For more technical details see the publications in the references.

4 The Results

In the following table we have summarised first all the Swedish results from the means of three double runs across the Öresund. This results are from Motorised Levelling with Zeiss Jena Ni 002A. The results show the extreme high precision obtained from coast to coast over a distance from more than 15 km. The maximum dispersion is 2,4 mm over this distance and the average uncertainty is 1,6 mm.

The last column shows the results from all kind of measurements (without any rejection): ML and MTL both Danish and Swedish. There again the dispersion is only few millimetres

FROM COAST TO COAST OVER ÖRESUND BRIDGE April 2000

Part	Distance	BM NR		m Mean 1	m Mean 2	m Mean 3	Swedish Av. mean	***Danish + Swedish***
East Br.	3750m	500503	430261	47,5913	47,5917	47,5943	47,5924	47,593
				1,1mm	0,7mm	-1,9		
High Br.	1092m	430261	410261	0,0592	0,0601	0,0601	0,0592	0,059m
West Br.	3012m	410261	300511	51,5027	-51,5041	51,501	-51,5026	-51,501
				-0,1	-1,5	1,6mm		
Artificial Island	4055m	300511	300501	18,6856	-18,6821	18,6836	-18,6838	-18,682
				1,8	-1,7	-0,2		
Tunnel	3514m	300501	100501	1,2515	1,2488	1,2478	1,2494	1,25
				-2,1	0,6	1,6mm		
Total=	**15,4 km**	500503	100501	21,2863	21,2856	21,2824	**21,2848**	21,281

	1,5mm	0,8mm	-2,4	1,6 mm

The Swedish & Danish ML teams on the High Bridge

This picture illustrates the inauguration of the Joint Nordic Project by the DG. Joakim Ollén (NLS-Sweden) and Dr Niels Andersen (KMS-Denmark)

5. Conclusions

The results from the height connections between Denmark and Sweden over the Öresund Bridge have confirmed that the classical Motorised Levelling Technique (ML):

- Is the most efficient levelling technique for such purpose
- Achieve millimetre "accuracy "(precision) over more than 15 km (including 8 km bridges)
- Is able to perform high precision under very difficult environmental conditions (Wind, low temperatures) where other techniques cannot be used.

We recommend this technique for other similar projects.

References

ANDERSEN OB. & Al (1986): Water Crossing Levelling between Denmark and Sweden 1980-1981, Köpenhavn, Geodetisk Institut, Skrift 3, Bind XLV- 1986

BECKER J-M (1990): Comparisons between different height determination techniques: Workshop on Heights, Hanover October 1990

BECKER J-M & Al (1988): Experience with Motorised Trigonometric Levelling, LMV-Rapport 1988:23

BECKER J-M (1997): Riksavvägningsarbeten i Sverige under perioden 1974-1995, LMV-Rapport 1997:2, ISSN 0280-5731

BECKER J-M (2001): The Height Connection between Denmark and Sweden over Öresund, 5th Conference on Optical 3-D Measurement Techniques, Vienna Oct. 1-4 2001

BREUMSÖ S.E ((2001): Deformation measurement on Bridge and Tunnel of the fixed link between Sweden and Denmark, The 10th FIG International Symposium on Deformation Measurements, 19-22 March 2001, Orange California, USA

ERIKSSON P.O. (2001): The Danish-Swedish Precise levelling Across the Öresund Connection, Workshop on height determinations, Akranes Iceland June 2001

KASSER M. & J-M Becker: Error sources in High Precise Levelling- How to minimise their effects on the heights, FIG seminar in Gävle, Mars 15-17th 1999.

Biographical notes.

Jean-Marie Becker is chair of FIG Commission 5 (Positioning and Measurement), chair of NKG WG for Height determinations and member of ISO/TC172/SC6 standards for Geodetic and Surveying Instruments. He is former head of Geodetic Production Division, National Land Survey of Sweden and developer of ML, MTL, and MTL techniques. He was responsible for the realisation the Swedish Height Network. He is former professor in engineering survey at the Royal Institute of Technology (BMG) Gävle/Stockholm. He is at present retired but still working with international questions.