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TecHnical RepoRT no. 1

Measurement and Computation of the new Oeresund Loop

By Casper Jepsen and Klaus Schmidt

DANISH MINISTRY

OF THE ENVIRONMENT

National Survey and Cadastre

Measurement and Computation of the new Oeresund Loop

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Measurement and Computation of the new Oeresund Loop

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Technical report handed over to the NKG Working Group for Height determination at the meeting in Akranes, Island, June 13-14, 2005

***Abstract.*** *In order to connect the height systems of Denmark and Sweden the Sound has been crossed repeatedly in the past at its northernmost end. From this, two small local loops could be set up from optical and hydrostatic water crossings. However, due to the recent completion of the Oeresund Link a new crossing could be established at the southernmost end of the Sound, giving for the first time the possibility to close a loop around the Sound. The crossing has been accomplished by motorized leveling in the year 2000 as a joint enterprise by National Land Survey of Sweden (NLS) and National Survey and Cadastre of Denmark (KMS).*

*The setup of the new loop is carefully defined and a description of all measurements involved is given. The measuring quality of the new crossing is shortly analyzed and compared to the Danish Third Precise Leveling. Based on the closing errors of the new loop and a local loop, which can be set up from an optical crossing and a hydrostatic leveling as well, conclusions are drawn on the reliability of the crossings involved and their usefulness for connection of the national height systems.*

*For the sake of consistency gravity has been applied to the leveling, however, for practical purposes the effect is almost insignificant. This also goes for postglacial land uplift corrections.*

***Acknowledgement:*** *Thanks to our Swedish colleagues from the NLS for providing the Swedish leveling data, in particular to Per-Ola Erikkson always available to answer new questions. Thanks also to J. Mäkinen from the Finnish Geodetic Institute (FGI), delivering the uplift grid, K. Johansen (KMS), setting up the on-shore leveling line from the Danish Third Precise Leveling, and G. Strykowski (KMS) for discussing gravity reduction using the GeoGrid program.*

# Introduction

* + 1. **Historical background.** In order to connect the height networks of Sweden and Denmark, i.e. the connection of the continental European networks with the networks of the Nordic countries, the Sound has to be crossed. Nowadays, this possibly could be achieved with sufficient accuracy by GPS, formerly, however, other solutions had to be found. Thus, the Sound was crossed by two optical water crossings and a hydrostatic leveling all carried out at the narrowest place (5km) at the northernmost end, Helsingør/ Hälsingborg. (For the sake of completeness three additional optical crossings from 1896/1898 and 1981 should be mentioned, se the references below. However, all of them are of doubtful quality.)

The first optical water crossing connecting the national First Precise Leveling networks took place as early as in 1896/1898, cf. the crossing K-T in Den Danske Gradmaaling (1909). As such crossings can be highly affected by deflections of the vertical as well as asymmetrical refraction the national Second Precise Leveling networks were connected by a hydrostatic leveling in 1939, cf. Nørlund (1946). Indeed, comparing these crossings a major deviation of 17mm turned out, ibid. p.81. Of course, this could be caused by poor quality of the optical crossing, but on the other hand the Sorgenfrei/Tornquist fault zone, separating the Fennoscandian Shield from the Norwegian Danish Basin, is crossing the Sound just in the area considered, cf. figure 1. Thus, irregular vertical movements of the reference benchmarks, occurred in the intervening time span of about 40 years, could not be excluded. Besides, due to the postglacial Fennoscandian land uplift, cf. Ekman (1996), there are no stable points in the Nordic countries. Nevertheless, if this is the only cause of a point’s vertical movement we shall use the term “stable” throughout this report.

In order to investigate this further a new optical crossing, recorded in Bedsted Andersen et al. (1986), was established in 1980, by the Danish Geodetic Institute (G.I.) and the Swedish NLS. As decided by the Leveling Working Group of the Nordic Geodetic Commission (NKG) the new crossing was designed as a repetition of the old one performed under the same conditions, as far as possible. Supposing this would imply the same systematic errors the difference of both crossings, based on a time span of about 100 years, could give an indication of the stability across the Sound. This concept possibly has been successful, because recomputing the old crossing and comparing it with the new one from 1980 a deviation of just 2mm was found, cf. Bedsted Andersen et al. (1986), p.35. As this result is subject to an estimated mean error of 5mm it was concluded “that no detectable relative height movements have taken place across the Sound from 1896 up to now (1980)”. However, the deviation is based on the somewhat doubtful leveling from 1984 in table 6; using the value from 1980/81 instead the difference would be 7mm.



figure 1: Location of the Sorgenfrei-Tornquist zone in the area of the Sound, from Abramovitz, T. et al. (1997)

* + 1. **Purpose and planning of the new measurements.** In the year 2000 a new possibility to cross the Sound came into existence due to the completion of the Oeresund Link (16km) connecting the cities of Copenhagen and Malmö, cf. sect. 1.3 for constructional details. Based on a proposal of the Height Determination Group of the NKG in summer 1999, a common decision was made by NLS and KMS to use the Link for the connection of the new national Third Precise Levelings conducted during the last two decades. If the height determination along the Link could be done with sufficient accuracy the height connection between Sweden and Denmark would be strengthened. Moreover, connecting the Link to the new leveling lines along the Sound and using the optical crossing from 1980 it would be possible for the first time to close a loop around the Sound, cf. figure 2, in order to check measuring quality. Hence, the primary goal of this report is the computation of the closing error taking into account postglacial uplift of the benchmarks

occurred within the measuring time span of the loop. Moreover, we shall compute the closing error of the local loop at Helsingør/Hälsingborg, which can be set up from the optical crossing (1980) and the hydrostatic leveling.



figure 2: The Oeresund Loop and its points for temporal connection

As the networks to be connected are coming from motorized geometric leveling it was clear from the beginning that the height determination of the Link should be conducted in the same way. For control purposes the measurements on the high bridge should be supplemented by motorized trigonometric leveling with sight lengths up to 500m to avoid all the intermediate setups needed for geometric leveling. However, due to the open sea strong wind is frequently occurring in the area. Also, heavy machines for road construction would be working during the measurements. Thus, it was doubtful if the leveling could be done with sufficient accuracy within the short period of time granted by the Oeresundsbro Konsortiet. Nevertheless, the completion of the Link was a one-time opportunity to strengthen the height connection across the Sound, therefore the measurements were started in the beginning of April, 2000.

* + 1. **The construction of the Link.** According to information from the Internet, [www.oeresundsbron.com](http://www.oeresundsbron.com/), the Link is consisting of a 4 km long tunnel, an artificial island, Peberholm (4 km), and an 8 km long bridge made up by the western approach bridge (3 km), the cable-stayed high bridge (1km) with a free span of 490 m, and the eastern approach bridge (4 km), cf. figure 3. The tunnel is necessary for security reasons due to the airport of Kastrup nearby.



figure 3: High Bridge and approach bridges of the Oeresund Link

Inside the tunnel (width 40m, height 7m, lowest point -20m) a 4-track motorway and a double track railway are running side by side through 4 tubes immersed in a ditch at the bottom of the sea and covered by stones. The soil from the immersion of the tunnel has been reused to build up the island of Peberholm, surrounded by shallow water and measuring about 300m across. The island is needed for the transition of the four tunnel tracks to the two levels of the bridges with the motorway on the upper deck about 10m above the railroad level. Motorway and railroad deck are connected through a stiff steel framework. The approach bridges are supported by piers, whereas the high bridge (max. height 70m) is tied to two pair of pylon legs, 204m high.

# The measurements

* + 1. **On-shore levelings.** Except for a short line of precise geometric foot leveling, connecting the optical crossing from 1980 and the Danish leveling network of that time at Helsingør, the on-shore lines of the new loop are part of the national Third Precise Leveling networks. Both networks have been measured by geometric motorized leveling, cf. Becker (1987), i.e. rods and level are moved by vehicles specially designed for transportation, and levels of the type Zeiss NI 002 as well as calibrated invar rods are applied in accordance with the Nordic guidelines for leveling, cf. Becker and Bedsted Andersen (1986). As regards precision motorized leveling is comparable to foot leveling, i.e. a mean error of about 1mm of 1km double run as found from the adjustment of the Danish Third Precise Leveling, cf. Schmidt (2000). However, productivity, essential for the measurement of the Link, is much higher, say, 2 km single run per hour.

In precise leveling the proper observation of a section height difference is a double run, i.e. the mean of one measurement (single run) in either direction. On location the discrepancy ρ between forward and backward run is tested. If the absolute value of ρ’ = ρ / L is exceeding a certain limit k both runs are rejected and a new double run has to be measured. Here ρ is in mm, L is the section length in km, and k=1.8

or k=2.0 for Danish or Swedish leveling.

* + 1. **The Link.** The leveling of the Link has been accomplished by one team from either country, using the same procedures and equipment as for the national Third Precise Levelings. The work took place within 8 days in chilly weather (3-8 C˚). Even though the leveling was planned from day to day in accordance with the weather conditions some of the measurements had to be conducted under difficult circumstances, e.g. strong wind in plain sunshine.

Wherever permitted by the Oeresundsbro Konsortiet proper leveling bolts were established by the national road authorities. Otherwise, removable bolts in the tunnel or tops of solid vertical screws were used for leveling control. Along the approach bridges the control points were pointed out on every second pier corresponding to leveling sections of 480 m length. Stable leveling points kept in the database of KMS are indicated by bold types in table A4. Of course, the piers were used for support of the level and the rods during the leveling. As a rule, neighboring leveling points were connected by 5 or 6 double runs.

Trigonometric leveling of the high bridge was carried out by an extra Danish team. The results were in good agreement with the geometric leveling, thus it was concluded that the latter was influenced by vertical movements much less than expected. For different reasons the trigonometric results have not been used in our computations.

Finally, as recorded by R. Forsberg (KMS) gravity was measured at 6 new points, cf. app.2, sect.2.1, in order to improve gravity interpolation along the Link, which is necessary for a consistent leveling adjustment.



figure 3.1: Motorized leveling on the High Bridge

* + 1. **The optical water crossing (1980).** The crossing performed during 2 weeks in the autumn of 1980 is connecting the top of the Telegraph Tower of the Castle of Kronborg with the top of the cliff of Pålsjø, a few kilometers north from Hälsingborg, cf. figure 4. These sites have been used, too, for the first optical crossing. They are located at a maximum height (30 m) above sea level in order to lessen asymmetrical refraction at the observation sites.

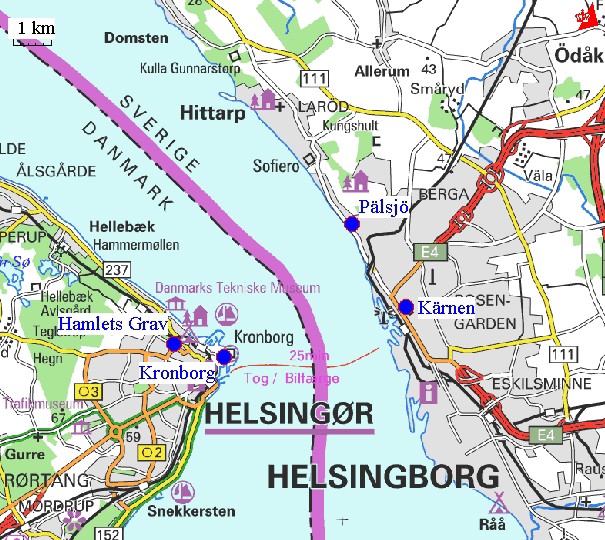


figure 4: Special locations in the area of Helsingør/Helsingborg

The crossing has been accomplished applying the so-called fjord crossing method often used in Norway,

i.e. the height angles of a pair of special target plates, attached to a leveling rod raised close to the opposite site, are measured simultaneously from both sites by means of the scale of the tilting screw of a Wild N3 level, cf. figure 5. From this, the height difference of the sites’ reference benchmarks can be computed twice. As can be shown each of these values, which are affected by the earth’s curvature, the level’s collimation error, and refraction, can be interpreted as an ordinary leveled setup height differences (backward - forward reading) with leveling rods fictitiously raised at the reference benchmarks, however, the sight lines are of very different lengths. Further details on measurements and computations can be found in Bedsted Andersen et al. (1986).



figure 5: Optical water crossing from the top of Telegraph Tower aiming to the signal plates in Sweden

It turned out from the computations that the height angles were highly affected by unsymmetrical refraction. Consequently, all readings taken under unfavorable meteorological conditions, i.e. about half of the entire number, were excluded from the final computation.

Last but not least, the benchmark on top of the Telegraph Tower had to be connected to the existing leveling network by measuring its height above the benchmark at the bottom of the tower. This was achieved through a vertical steel tape connecting both points. The length of the tape corresponding to a given traction and temperature was found from interferometer measurements.

# Lining up the Oeresund Loop

* + 1. **The points for temporal connection.** In order to set up the loop leveling lines from different decades had to be connected. Wherever these levelings are overlapping any point of the overlap could be chosen for connection, however, the vertical movement of the connection point should be estimable as good as possible, cf. sect.5. With this in mind the connection points, shown in fig.2, have been carefully selected.

On the Danish side points preferably joining a group of subsoil benchmarks should be used for connection purposes. Frequently, the benchmarks of such group are standing in a row within a short distance, say, 50m. They always are leveled jointly to monitor vertical stability. In general, a subsoil benchmark is consisting of a well-founded granite pillar or a concrete block, the top of which is up to 1½m beneath the ground. Its proper motion (relative to the surrounding soil) is expected to be insignificant. Also, movements, which are nonlinear in time, are unlikely. Thus, subsoil benchmarks are considered as the most stable kind of leveling marker in Denmark.

Due to the lack of measurements there is no subsoil point in the area of Copenhagen to connect the Link with the Danish Third Precise Leveling. Anyhow, there are three different bolts, which could be used. Among them we have selected the bolt K -01-06817 located at the old, massive building of the Castle of Christiansborg (The Danish Houses of Parliament). According to preliminary results from the computation of land uplift in Denmark based on the three Danish Precise Levelings, the bolt seems stable relative to the nearest subsoil benchmark G.M.1393. However, both points could be on unstable ground, because they are close to the sea in a few meters height. Nevertheless, the bolt also seems stable relative to the remote subsoil group G.I.1803-1806 located inland close to the former Geodetic Institute’s laboratory.

In the Helsingør region the connection of the Third Precise Leveling and the optical crossing (1980) is complicated by inconsistent leveling results as recognized already in Bedsted Andersen et al. (1986), sect.II,

1.2.2. Investigating the levelings from 1940 on, cf. app.2, sect.1, the connection point finally chosen is the benchmark G.I.1607 of the subsoil group Hamlets Grav, se fig. 4.

In addition, several lines from the Swedish Third precise leveling had to be joint in order to connect the Helsingborg area with the Link. The points of connection, 032\*1\*3124, 022\*1\*6515, and 022\*1\*2423, have been pointed out by our Swedish colleagues claiming stability of these points in the last few decades.

* + 1. **Debugging the Link.** It was obvious from the data delivered by NLS that the rejection limit of precise leveling, cf. sect. 2.1, had not been applied to the Swedish double runs of the Link. Catching up on this we noticed a rather large number of severe rejections on the eastern approach bridge. It could be shown from a closer investigation that this was caused by 2 leveling points, 4078/500 501 and 4078/500 502, both alternately moving within a few millimeters between 2 vertical positions depending on the day of observation. According to the leveling teams, this probably can be explained through heavy machines for road construction working close to these points on some of the days. In our computations we have used additional point numbers, i.e. the original ones extended by .1, to distinguish between both positions. However, due to some rejections the point 4078/500 502.1 became the end point of an antenna, therefore it will not occur in this documentation. It should be mentioned that point numbers of the type 4078/…are referring to the numbering system adopted by the national road authorities,
    2. **Configuration.** Apart from the optical crossing the loop has been set up entirely by double runs obtained from single runs in the national data files, the latter corrected for scale graduation errors and temperature. All the double runs included have been accepted according to sect. 2.1 except for a few runs outside of the Link. Repeated double runs have been included separately, antennas have been removed. Along the Link the loop is consisting of line-shaped networks connecting the different sections of the Link, such that neighboring networks have just 1 point in common. Outside of the Link the loop is consisting of consecutive double runs without crossovers and just a few repetitions.

In total, the loop has been set up from 315 points connected by 502 double runs, in addition to the optical crossing from 1980 and the corresponding steel tape measurement. Double runs are listed at the end of this report. The circumference of the loop is about 192 km, but due to the large number of repeated double runs along the Link the accumulated length of all double runs involved is about 254 km (76 km along the Link).

A schematic outline in clockwise order is given in table 1. Bold point numbers are indicating the connection points in fig. 2. In case of leveling ΣL is denoting the accumulated length in km of the double runs included. The ΔĤ-values below are adjusted Helmert height differences according to sect. 4.2, except for the water crossing, which is orthometrically corrected, whereas the corresponding steel tape measurement is uncorrected. The sources are referring to the Swedish Third Precise Leveling data, the KMS leveling data files #DK\_niDniv and #DK\_niDprs, the G.I. field book GA.I, vol. 102, and Bedsted Andersen et al. (1986).

location point no. ΔĤ method ΣL year data source

**Hamlets Grav G.I.1607**

-13.65976m geom..foot lev. 2.8 1980 #DK\_niDniv & GA.I, bind 102,

p.128916, 128918

GA.I, bind 102, p.129142

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Telegr. tower, foot | K –06-09008 |  | | | |
|  |  | 21.7468 | steel tape | 0.022 | do. |
| Telegr. tower, top | K –06-09170 |  |  |  |  |
|  |  | -0.59106 | opt. water cr. | 4.8 | do. |
| Pålsjø Cliff | 032\*2\*3116 |  |  |  |  |
|  |  | 2.23258 | geom..mot. lev. | 3.1 | 1980/81 |
| **Kärn., found.wall** | **032\*1\*3124** | -15.44517 | do. | 58.4 | 2001/02 |
|  | **022\*1\*6515** | -1.33355 | do. | 32.2 | 1983 |
|  | **022\*1\*2423** | 3.48312 | do. | 6.4 | 2000 |
| Link, start | 4078/500 503 |  |  |  |  |
|  |  | -21.28167 | do. | 75.8 | do. |

Bedsted A., p.30 Sw. 3rd prec. lev.

do.

do.

Link, end 4078/100 501

**Christiansborg K –01-06817**

do.

#DK\_niDniv & Sw. 3rd prec.lev.

5.52243 do. 14.5 1998/2000 #DK\_niDniv

19.31278 do. 60.5 1992 #DK\_niDprs

**Hamlets Grav G.I.1607** ------------ -------

-0.01350 258.5 km

table 1: Set up of the Oeresund Loop

# Analysis and adjustment

* + 1. **Double run discrepancies.** In order to compare the leveling of the Link with the Danish Third Precise Leveling we have computed sectionwise the average (av) and standard deviation (std) of the normalized discrepancies ρ’, cf. sect. 2.1, from all the double runs of the loop included in the Link. As mentioned before all these runs have been accepted. The results are shown in table 2, where the last row is indicating the percentages of rejected double runs based on the total number of runs performed along the Link (accepted or not).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| location: | east bridge | high bridge | west bridge | Peberholm | tunnel |
| av(ρ’) : | 0.25 mm | 0.28 | 0.49 | -0.11 | -0.11 |
| std(ρ’) : | 0.77 mm | 0.87 | 0.76 | 0.99 | 0.97 |
| number : 59 | | 15 | 59 | 32 | 64 |
| reject. pct.: 13 | | 21 | 9 | 14 | 2 |

table 2: Statistics of double run discrepancies

According to Schmidt (2000), sect.3223, the rejection percentage of the Danish Third Precise Leveling is below 5%. Hence, the values above are larger than usual, however, the indicated averages and standard deviations of ρ’ are rather common. In particular, the standard deviations along the bridges are almost identical with the average value 0.75 mm from the Danish Third Precise Leveling, cf. sect. 5322, ibid. We thus conclude that the leveling of the Link after rejection is comparable with the Danish Third Precise Leveling as regards discrepancies from forward and backward run.

* + 1. **Adjustment.** Based on the assumption that all double runs are stochastically independent the loop can be adjusted in a simple way. Regarding the Link least squares adjustment is applied separately to the different networks connecting the sections of the Link, cf. sect. 3.3. That means, keeping fixed à priori the height of a single point of the network, ΔH12=H2-H1 is the observation equation of the double run from point P1 to P2 of length L, and VarΔH12=σ2L is the corresponding variance. Outside of the Link multiple double runs have been adjusted by their mean. Note, prior to the adjustments double runs have been converted into Helmert height differences by adding the orthometric correction, cf. app.1, sect. 2.1 and 2.3.

The results from the sectionwise adjustments are shown in table 3, where ΔĤ is the adjusted Helmert height difference, m.e.(ΔĤ) is the corresponding estimated mean error, s is denoting the estimated mean error of 1km double run, whereas n and m is the number of double runs and leveling points involved. The last row is indicating the adjusted Helmert height difference of the Link and the corresponding estimated mean error, that is the square root of the sum of the m.e.(ΔĤ)-values squared. Note, the surprisingly low value, 1½mm, is caused by the large number of repeated double runs, cf. sect.2.2.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| location | point no. | ΔĤ | m.e.(ΔĤ) | s | n | m |
|  | 4078/500 503 |  |  |  |  |  |
| east bridge |  | 47.59273m | 0.77mm | 0.77mm | 59 | 19 |
|  | 4078/430 261 |  |  |  |  |  |
| high bridge |  | 0.05892 | 0.63 | 1.21 | 15 | 4 |
|  | 4078/410 261 |  |  |  |  |  |
| west bridge |  | -51.50084 | 0.72 | 0.87 | 59 | 14 |
|  | 4078/300 511 |  |  |  |  |  |
| Peberholm |  | -18.68245 | 0.63 | 0.72 | 32 | 8 |
|  | 4078/300 501 |  |  |  |  |  |
| tunnel |  | 1.24997 | 0.48 | 0.51 | 64 | 14 |
|  | 4078/100 501 | ------------ | -------- |  |  |  |
|  |  | -21.28167 | 1.46 |  |  |  |

table 3: Results from the sectionwise adjustments of the Link

According to Schmidt (2000), p.31, s-values in the range from 0.6 to 1.0 are expectable, thus the values above are quite common. As regards the rather large s-value of the high bridge point movements during the leveling could not be detected from the data, more likely, the value is caused by a single doubtful double run, which, however, had to be accepted according to sect.2.1.

The loop closing error has been computed by summing up the height differences in table 1. As is seen a value of -13.50 mm has been obtained. Also this is in good agreement with the Danish Third Precise Leveling. The mean error of the computed closing error can be sufficiently estimated from the dominating contribution from the on-shore leveling lines, the length of which is the length of the loop (192km) minus the length of the Link (16km). Assuming a mean error of 1 mm per 1 km double run the estimated mean error of

the closing error is ≈ 13 mm.

192  16

Finally, with reference to possible future remeasurements of the Link, we give the adjusted height differences Δĥ between the stable leveling points recorded in the files of KMS. The Δĥ-values of table 4 are coming from ordinary adjustments of measured double runs, i.e. without applying orthometric corrections.

point no. 4078/: 500 503 400 506 400 502 300 511 300 502 300 501 100 502 100 501

Δĥ : 49.40225m 0.02898 -53.28031 -16.26851 -2.41392 -1.55703 2.80697

lev. distance : 4.3km 0.5 4.0 3.1 0.1 4.2 0.1

table 4: Adjusted height differences of selected points of the Link

Still ignoring these corrections a loop closing error of -12.94 mm has been found, in addition to the adjusted height difference of the Link, Δĥ = -21.28157 m. Comparing this with the results above it is obvious that the effect of the orthometric correction is insignificant from a practical point of view.

# Loop closing errors and land uplift

The closing error in sect.4.2 has to be corrected for vertical movements of the connection points. In order to derive a correction formula consider the loop in the figure to the left composed of leveling lines from different years ti connecting the points Pi, and let ΔH’i,i+1(ti)=ΔHi,i+1(ti)+dε denote the corresponding orthometric height differences, where ΔHi,i+1(ti) is the true value and dε the error induced from leveling. Assuming linearity of the movements given by annual uplift rates ai, it holds

ΔHi,i+1(ti) = ΔHi,i+1(to) + (ai+1 - ai)(ti - to )

where to is a certain reference year adopted à priori. Summing up along the loop the sum ΣΔHi,i+1(to) is vanishing, since orthometric heights are consistent, cf. app.1, sect. 2.1. Hence, let ao be any constant value, then it can be easily shown that the closing error corrected for vertical movements can be written

Σdε = ΣΔH’i,i+1(ti) -Σ(ai - ao)(ti-1 - ti)

Note the equation is not depending on the reference year to. Obviously, the larger the time span (ti-1, ti) the better an estimate of uplift is needed.

Annual uplift rates relative to mean sea level can be computed at specific points from repeated leveling and sea level observations. However, final values in the Oeresund region computed by the national surveying authorities are not available, yet. Nevertheless, established by Ekman (1996) there exists a continuous model of Fennoscandian postglacial uplift relative to mean sea level, which we have used in our computations. Other models possibly more refined are available, but no matter which model is chosen it cannot provide the actual uplift of specific points, if they are affected by local movements or proper motions. This is the reason why the connection points of the Oeresund Loop have been selected so carefully.

The uplift values applied have been interpolated from a numeric grid based on Ekman’s map and handed over to the Height Determination Group by J. Mäkinen (FGI). They are corresponding to (ai-ao) in the formula above, where ao is the uplift of the mean sea level. The values in mm/y are given in the table below.

Hamlets Grav Kärnan, found. wall Kärnan, tower chamber Christiansborg G.I.1607 032\*1\*3124 032\*2\*3109 022\*1\*6515 022\*1\*2423 K -01-06817

-0.13 -0.11 -0.11 -0.23 -0.34 -0.33

table 5: Annual uplift rates from Ekman

Using the measuring years from fig.2 we get from table 5, Σ(ai-ao)(ti-1-ti)=-0.25mm, i.e. the closing error in sect.4.2 is practically unchanged. Hence, we conclude the closing error corrected for postglacial land uplift is about -13mm, but recall, proper motions e.g. are not taken into account.

# The loop set up from optical and hydrostatic water crossing

To line up the loop the crossings have to be connected by local leveling lines, among others the line from Pålsjø Cliff to Kärnan, cf. fig. 4, which has been measured repeatedly in the past. The results are given below. Note, the value from 1984 seems unreliable and is not used.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1896/97 | 1939 | 1956 | 1980/81 | 1984 |
| 9.217 m | 9.21735 | 9.2176 | 9.21976 | 9.2247 |
| source: Bedsted A., p.21 | Nørlund, p.25 | NLS | Sw.. 3rd prec. lev. | Bedsted A., p.21 |

table 6: Height differences from Pålsjø Cliff to Kärnan, tower chamber

An outline of the loop is given in table 7, where the connection points are indicated by bold types. The Δĥ- values are adjusted measured height differences without applying orthometric corrections. The circumference of the loop is about 17 km and a loop closing error of -2.13 mm has been found from summing up the height differences. From table 5 we get, Σ(ai-ao)(ti-1-ti)=0.80 mm, i.e. the closing error corrected for postglacial uplift is about -3mm.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| location | point no. | Δĥ | method | year | data source |
| **Hamlets Grav** | **G.I.1607** | -13.65975m | geom..foot lev. | 1980 | cf. table 1 |
| Telegr. tower, foot | K –06-09008 |  |  |  |  |
|  |  | 21.7468 | steel tape | do. | do. |
| Telegr. tower, top | K –06-09170 |  |  |  |  |
|  |  | -0.5903 | opt. water cr. | do. | do. |
| Pålsjø Cliff | 032\*2\*3116 |  |  |  |  |
|  |  | 9.21976 | geom..mot. lev. | 1980/81 | table 6 |
| **Kärn., tower** | **032\*2\*3109** | -35.81085 | geom. foot lev. | 1939 | Nørlund, p.24 |
|  | 0-ref. point (S) |  |  |  |  |
|  |  | -0.01137 | hydrostatic lev. | 1939 | Nørlund, p.79 |
|  | 0-ref. point (DK) |  |  |  |  |
|  |  | 1.05335 | geom. foot lev. | 1939 | Nørlund, p.22 |
| City Hall | K –06-09011 |  |  |  |  |
|  |  | 18.94986 | do. | 1940 | Nørlund, p.23 |
| Hamlets Grav | G.I.1606 |  |  |  |  |
|  |  | -0.89963 | do. | 1940 | G.I. comp.vol., p.2077 ff. |
| **Hamlets Grav** | **G.I.1607** | ----------- |  |  |  |
|  |  | -0.00213 |  |  |  |

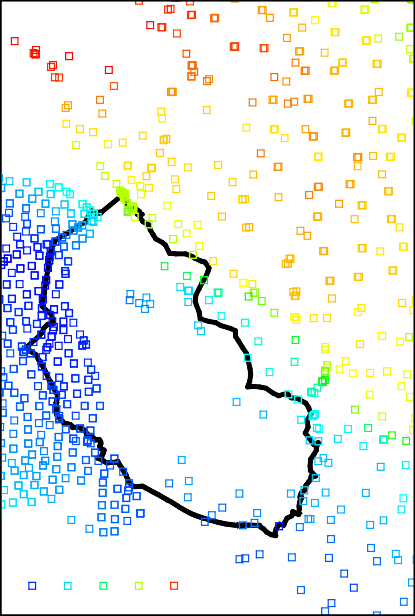
table 7: Set up of the loop from optical and hydrostatical crossing

# Gravity processing.

* + 1. **Preliminary remarks.** According to theory leveling should be computed from geopotential or orthometric height differences (both are based on gravity), but not from the field measurements, cf. app1, sect. 2.1-2.3. However, it turned out that this did not really matter, cf. fig. 8.

As we know from the Danish Third Precise Leveling the deviations of leveled height differences from corresponding orthometric height differences are hardly summing up along a loop in a low and flat area with smooth gravity like the Oeresund region. Moreover, they normally are rather small, say, less than 0.1mm per km. However, gravity behaves irregular in the area of Helsingør/Hälsingborg, cf. fig.6. In addition, the leveling of the Link certainly is incomparable with normal leveling, since measurements have been performed not only on the ground but also on the bridges and in the tunnel.

Due to these considerations we have decided to apply the strict approach, i.e. leveling combined with gravity, even though this makes the computations a good deal more cumbersome. In the present case we have used orthometric height differences, because the orthometric corrections immediately are illustrating the effect of gravity on leveling.

* + 1. **Particular circumstances.** Usual textbooks on leveling are referring to leveling on the ground, thus the common computation formulas of Bouguer anomalies, gravity interpolation, and mean gravity along the plumb line had to be modified for the measurements on the bridges and in the tunnel of the Link. Computed from form. (9.3) in Blakely (1996) gravity contributions from the tunnel or the pillars/pylons of the bridges are less than 1 mgal, therefore they have been ignored in all our computations. Consequently, points on the bridges have been considered as points in free air above the sea, i.e. case [c], cf. app.1, sect.4 - 6, on Peberholm as case [d], ho=5 m, and in the tunnel as case [e], t1>0,

except for the endpoints, case [e], t1<0. In addition, the point on top of the Telegraph Tower, as case [d], ho=21.75 m.

Furthermore, ground density ρ=2.00 g/cm3 has been used in all our gravity computations. As is seen from fig.6 ground conditions along the Oeresund Loop are more or less similar on both sides of the Sound, except for the Hälsingborg area, thus the traditional Danish density value above has been used in the entire region. Anyhow, the more common value ρ=2.67 could have been used, too, this does not really matter.

* + 1. **Bouguer anomalies applied.** Fig. 6 is showing the Bouguer anomalies (ρ=2.67) available in the Oeresund region extracted from the NKG gravity database for gravity interpolation. Points from marine gravity as well as the new gravity points along the Link are not shown. As is seen the anomalies between Helsingør and Hälingborg are increasing about 24 mgal, which is indicating an uplift of the bedrock underneath Hälsingborg. In general, the anomalies on the Swedish side are growing in north-east direction, which is in good agreement with the north-west direction of the bedrock ridges Kullen (altitude 188 m) and

188 m

-20 -10 0

15 30 mgal

212 m

Söderåsen (212 m). Fig. 6: Bouguer anomalies in the Oeresund region

For the sake of consistency the anomalies in fig. 6 have been transformed into values corresponding to ρ=2.00, taking into account that the data points are either on the ground above the geoid or at the surface of the sea (from marine gravity), which is indicated by positive or negative heights in the database. The latter is referring to the (negative) depth of the sea. The transformation formula is given in app.1, form. (12). In addition, we have computed the Bouguer anomalies (ρ=2.00) of the new gravity points along the Link. Measured gravity and results are given in app.2, table A3.

* + 1. **Gravity interpolation.** Applying the strict approach a gravity value is required at every leveling point. Based on the transformed Bouguer anomalies (ρ=2.00) mentioned in sect.7.3 gravity values have been found applying the GeoGrid program, cf. app.1, sect. 5.1, running the job ‘nivtyng.bat’. Since ground density ρ=2.67 is used by the program the interpolated gravity values from GeoGrid had to modified (mod.1) according to ρ=2.00 using the formulas in app.1, sect.5.2. Furthermore, depending on the input height h any interpolation point is considered by the program either on the ground above the geoid (h>0) or at the surface of the sea (h<0, -h is the depth of the sea). That means applying the formulas, ibid., further modifications (mod.2) had to be done as regards the points of the Link and the point on top of the Telegraph Tower. Concerning the Link the final results gP\* are given in app.2, table A4.
    2. **Orthometric correction.** Mean gravities g P

have been computed from the formulas in app.1, sect.6,

using leveled heights. Hereafter, the orthometric corrections have been found from form. (6), app.1, using the average gravity value go=981500 mgal. The correction has been applied, too, to the optical water crossing, but not to the steel tape measurement.

In fig.8, bold curve, we have shown the differences between adjusted Helmert heights and the heights from an ordinary leveling adjustment starting at Hamlets Grav, where we have adopted the same initial height value. As is seen the impact of gravity on the adjusted heights is in the range of about ±1 mm. Also note the short segment (6km) north of Landskrona (Lk), where the differences are increased by almost 1½ mm. The jump at the beginning of the curve is coming from the orthometric correction (-0.76 mm) of the optical water crossing (w.cr. in fig.7). It is doubtful, if the computed value is strictly correct, since form. (6), app.1, is based on leveling with forward and backward sights of equal length, however, the sight lengths of the water crossing are extremely different, say, 50 m and 5 km. Disregarding the crossing and the segment mentioned above the curve behaves as expected, i.e. smoothly increasing from north to south and smoothly decreasing in the opposite direction, cf. app.1, sect.2.3. Nothing extraordinary is happening along the Link. Note also, the final value of the curve (-½mm) is indicating the deviation of the loop closing error applying gravity or not, cf. sect. 4.2.

80

m

60

40

20

0

-20

20

10

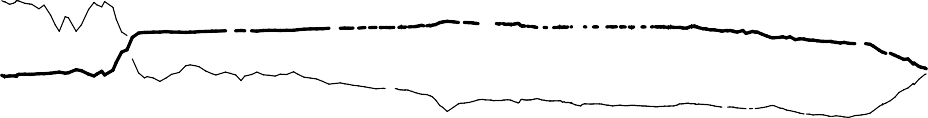
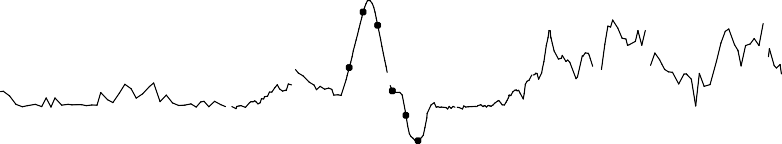
0

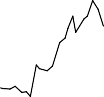
-10

-20

figure 7: Height profile of the Oeresund Loop

|  |  |
| --- | --- |
| DK Sweden Denmark | |
|  | |
|  |  |
|  |  |
|  | |
| G.I.1607 G.I.1607 | |

0 50 100 150 200 km



tunnel

w.cr

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | | | |
|  |  |  |  | diff. (Helmert - leveled heights) |
|  | | | | |
| Bouguer anomalies | | | | |
|  | | | | |
| Hb | Lk |  |  |  |

0 50 100 150 200

figure 8: Differences (Helmert heights – leveled heights) in 0.1mm vs. Bouguer anomalies in mgal

Additionally, we have shown in fig.8 the Bouguer anomalies (ρ=2.00) along the loop. Reflecting the depth of bedrock below the ground the anomalies are strongly increasing from Helsingør to the opposite side of the Sound, whereas a corresponding decrease is found along the line segment mentioned above.

# Conclusions

* Applying the usual rejection limit for leveling to the measurement of the Link, it is fully comparable to the Danish Third Precise Leveling. Thus, it should be used for the connection of the new height networks in Denmark and Sweden.
* The suspicion that the optical water crossing (1980) is defective cannot be confirmed by the closing errors corrected for postglacial uplift, neither from the Oeresund Loop (-13mm), nor from the loop including the optical and hydrostatic crossing (-3mm).

# Appendix 1: Leveling and Gravity

Normally, textbooks on leveling are only referring to leveling on the ground. In the following we try to substantiate the validity of the fundamental equations, cf. form. (3), (5), and (6) below, also for leveling on bridges or in tunnels. In this case, however, the common formulas for the computation of Bouguer anomalies, interpolated gravity, etc. have to be modified as shown.

## Geopotential numbers and orthometric heights.

To move a particle of mass in a three-dimensional force field from one point to another the work required generally is depending on the path taken by the particle. However, as can be shown the earth’s gravity

acceleration **g** can be written as the gradient Moritz and Heiskanen (1967), sect. 2-1

(W / x, W / y, W / z) of a real function W in space, cf.

**g =** gradW (1)

This is the fundamental equation for all what follows.

From (1) can be concluded due to the findings of Potential Theory that the work done by the gravity field is independent of the path. The function W is called the gravity potential of the earth, its value at the point P is the work done by the gravity field to move the unit mass from infinity to P, cf. Torge (1991), sect.2.1.1.

Due to (1) the work W2-W1 done by the gravity field to move the unit mass from point P1 to P2 is given by integrating the magnitude g of the gravity vector **g** along an arbitrary path connecting the points

P1

W2-W1 =  gdn

P2

(2)

Here dn is the elemental vertical displacement of differentially separated equipotential surfaces, W=constant, along the path, cf. Moritz and Heiskanen (1967), form. (4-4). The increment dn is counted positive in outwards direction, i.e. opposite to the gravity vector.

Let the geoid be given by the equipotential surface W=Wo then the geopotential number CP of any point P in space is defined by

CP=Wo-WP

Hence, CP can be interpreted as the work done by the gravity field to move the unit mass from the point P to the geoid. The unit of geopotential numbers is 1g.p.u.=1kgal·meter=10m2/sec2 according to the unit of acceleration 1gal=1cm/sec2.

A further consequence of (1) is that the gravity vector **g** at any point P is normal to the equipotential surface, W=WP, through P. Hence, **g** is tangent to the plumb line through P intersecting normally (by definition) all equipotential surfaces. Let Po denote the intersection point of the plumb line through P and the geoid W=Wo then the orthometric height HP of P is defined by the length of the plumb line section from Po to

P. Considering the latter as a path from Po to P it follows from (2) that geopotential number and orthometric height are related as follows, cf. Moritz and Heiskanen (1967), form. (4-19), (4-20), (4-21)

CP = g P HP

, HP

= CP

g

(3)

P

where g P (in kgal) is the mean value of gravity g integrated along the plumb line from Po (H=0) to P (H=HP)

1 *HP*

(4)

g P =

P

H

 *gdH*

0

As gravity approx. is 0.98 kgal in the area close to the earth’s surface geopotential numbers in g.p.u. are about 2% smaller than the corresponding orthometric heights in meter.

## Conversion of leveled height differences.

**2.1 The inconsistency of leveled heights.** According to above the elemental alteration dW of the potential W corresponding to a vertical elemental displacement dH at the point P is given by dW = -gPdH, cf. Moritz and Heiskanen (1967), form. (2-14). It follows, since gravity g is varying on the equipotential surface through P, that the surface is nonparallel to the neighboring equipotential surfaces. According to chapter 4.1, ibid., the nonparallelism of the equipotential surfaces has the following consequences

* + leveled height differences are depending on the leveling path between the endpoints
  + summing up leveled height differences along a loop the resulting closing error is not strictly vanishing, even if the leveling has been performed without any kind of errors
  + the usual observation equation for the adjustment of the leveled height difference from P1 to P2,

Δh12=h2-h1, is not strictly valid

That means, leveled heights do not constitute a consistent system. However, orthometric heights or geopotential numbers are free from the lacks above, thus, all leveling can be calculated strictly in the usual

way, replacing leveled height differences by geopotential or orthometric height differences. From (3) orthometric heights can be computed from geopotential numbers, and vice versa. If metric heights are not needed, say in the computation of loop closing errors, it is often more practical to use geopotential differences.

* 1. **Conversion into geopotential differences.** As outlined in Moritz and Heiskanen (1967), chapter 4.1., leveled height differences are yielding differences of geopotential numbers (geopotential differences), if combined with gravity. Under normal conditions it holds with sufficient accuracy

ΔC12 = C2 - C1 = Δh12gm (5)

cf. Moritz and Heiskanen (1967), form. (4-3), see also the derivations in Torge (1991), sect. 4.3.5, and Jordan/Eggert/Kneissl (1956/1969), § 135. Above Δh12 is the leveled height difference and gm (in kgal) is the arithmetic mean of gravity at the endpoints of the section. Studying the derivations in the textbooks mentioned before it can be seen that equation (5) is valid not only for leveling on the ground, but also for measurements on bridges or in tunnels.

* 1. **The orthometric correction.** Adding the orthometric correction OC12 to a leveled section height difference Δh12 the corresponding difference of orthometric heights ΔH12=H2-H1 is obtained. Form. (4-33) in Moritz and Heiskanen (1967) is giving the correction in case of leveling on the ground. As can be seen from its derivation it is valid, too, for leveling on bridges or in tunnels. In smaller regions at least, the formula can be written

OC12 =

gm  go Δh

go 12

* g1  go h

go 1

* g 2  go h

go 2

(6)

Here gm is again the arithmetic mean of gravity at the endpoints, go is an appropriate average value of gravity in the region, g is mean gravity defined through form. (4), and h is a preliminary height from leveling, e.g. In

order to compute the correction mean gravity gm has to be found from gravity interpolation, cf. sect.5, whereas g is calculated from sect.6. Strictly speaking, form. 6 is the so-called orthometric Helmert

correction giving Helmert heights when added to leveled height differences.

In case of leveling on the ground above the geoid can be shown that the orthometric Helmert correction referring to ground density ρ=2.00g/cm3 can be simplified as follows

OC12 = -hm(Δg12 + (0.3086 - 2·0.0838)Δh12 )/go (in m)

where hm is the arithmetic mean of h1 and h2 (in m) and Δg12=g2-g1 (in mgal) is the difference of gravity at the endpoints. As can be seen from the formula, in a low and flat area with smooth gravity the correction is summing up in the north-south direction, but hardly from east to west. Consequently, its impact on the closing error often is relatively small.

## Gravity reduction by means of Bouguer plates.

Given the points P and Q on the same plumb line gravity reduction from P to Q is the prediction of gravity at Q from gravity at P. Gravity reduction is needed for the computation of mean gravity g as well as Bouguer

anomalies ΔgBB used for gravity interpolation. The simplest method is the simplified reduction of Poincaré and Prey, cf. Moritz and Heiskanen (1967), sect.4-3. Though the reduction seems rather rough it is generally working well for leveling in low and flat areas with smooth gravity.

Say, gravity has to be reduced from P to Q. For this purpose the masses along the plumb line through P and Q are replaced by Bouguer plates, i.e. infinite plane horizontal plates with constant mass density, such that both points are on the surface of a such a plate. Assuming P is below Q gravity at Q is obtained according to the following steps:

1. Remove all the plates above P and compute the corresponding gravity at P
2. Move P through free air to Q and compute the corresponding gravity at Q
3. Restore the plates removed and recomputed the gravity at Q. An example is given below.

Obviously, removing a Bouguer plate located above/below a given point P is increasing/decreasing gravity at P by an amount corresponding to the plate’s vertical attraction on P, whereas adding a plate above/below the point is decreasing/increasing gravity at P. According to Moritz and Heiskanen (1967), form. (3-15), the attraction is given by

ABB = cρb mgal

where b (in meter) is the thickness of the plate and cρ is depending on the plate’s mass density ρ (in g/cm3). Thus, the attraction is independent from the distance of P from the plate. Common values of ρ and cρ are given below:

ground , standard value: ρ=2.67 g/cm3 cρ=0.1119 ground, Denmark: ρ=2.00 cρ=0.0838 sea water: ρ=1.03 cρ=0.0432

Note, due to the moraine and chalk densities of the Danish subsurface ground density ρ=2.00 is the traditional value for the computation of leveling in Denmark.

Finally, moving the point P to Q through free air the gravity change is given by F = 0.3086l mgal

where l (in meter) is the distance between P and Q, counted negative if P is below Q.

□ Example: Assuming the point P is below the bottom of the sea (assumed plane) let h denote the height of P and d the depth of the sea. Obviously, since h is negative, t1=-h-d is the positive height of the sea floor above P, cf. case [e] in sect.4. Furthermore, let P1 and Po be the points, where the plumb line through P is intersecting the bottom and the surface of the sea. Now, let s[0,t1] be the distance along the plumb line through P, counted positive from P in upwards direction. Applying the procedure above (ρ=2.00) gravity g(s) at the point corresponding to s is predicted from gravity gP at P by

g (s)=gP+0.0432d+0.0838t1 -0.3086s+0.0838s -0.0838(t1-s)-0.0432d = gP+(2·0.0838-0.3086)s (mgal)

Correspondingly, counting the distance from P1, s1=s-t1[0,d] gravity g(s1) is predicted from gravity g1 at P1 g(s1) = g1+0.0432d -0.3086s1 + 0.0432s1 – 0.0432(d-s1) = g1 + (2·0.0432 - 0.3086)s1 (mgal)

Hence, applying s=t1 and s1=d gravity at P1 and Po is given by g1 = gP + (2·0.0838 - 0.3086)t1 (mgal)

go = g1 + (2·0.0432 - 0.3086)d (mgal) □

## Bouguer gravity and anomalies.

In order to make gravity gP at a given point P comparable to what is ‘normal’ in accordance with a geometric/gravimetric model of the earth gravity is reduced from P to the intersection point Po of the plumb line through P and the geoid, assuming a fictitious solid geoid with no masses above. The term ‘solid’ means, e.g., seawater is replaced by soil. The reduced value gBB is the Bouguer gravity of P and its deviation from ‘normal’ is the corresponding Bouguer anomaly ΔgBB

ΔgBB = gBB – γo (7)

The ‘normal’ gravity value γo referring to the geodetic reference system GRS80 can be computed from form. (3.4) in Torge (1989), e.g. Obviously, Bouguer anomalies are reflecting the mass densities of the ground, which makes them suitable for gravity interpolation.

In the formulas below, derived in accordance with sect.3 applying ground density ρ=2.00, h is the height of the point P above the geoid/mean sea level and d is the depth of the sea at P’s location. Bouguer gravity gB is in mgal.

1. P on the ground above geoid:

gB=B gP - 0.0838h + 0.3086h (8)

Replacing 0.0838 by 0.1119, cf. sect.3, (8) is corresponding to Moritz and Heiskanen (1967), form. (3-18). Obviously, the Bouguer plate between P and the geoid is removed, hereafter P is lowered to the geoid through free air. Similarly, we find:

1. P at the surface of the sea:
2. P in free air above the sea:

gBB = gP - 0.0432d + 0.0838d (9)

gBB = gP – 0.0432d + 0.0838d + 0.3086h

1. P in free air above the ground above geoid: (ho is the height of P above ground)

gBB = gP - 0.0838(h-ho) + 0.3086h

1. P below the surface of the sea: (t1=-h-d is the height of the bottom above P)

P below the bottom, t1>0: gBB = gP + 0.0838t1 + 0.0432d - 0.3086(-h) + 0.0838(-h)

P above the bottom, t1<0: gBB = gP - 0.0432(-t1) + 0.0432(-h) - 0.3086(-h) + 0.0838d

## Gravity interpolation (GeoGrid)

* 1. **The GeoGrid program.** Gravity interpolation can be carried out by the GeoGrid program, which is part of the program package GRAVSOFT used for geoid computations, cf. Tscherning et al. (1992). Using ground density ρ=2.67 it proceeds as follows.
     1. The interpolated Bouguer anomaly ΔgB\*B of the point P is computed by the weighted mean of Bouguer

anomalies of 5 data points in each quadrant, which are closest to P. The weighting is done in accordance with the reciprocal squared distances of P from the data points applied (different options are available).

* + 1. The corresponding Bouguer gravity gB\*B is computed according to (7) using normal gravity of GRS80 gB\*B = ΔgBB\*+ γo
    2. Interpolated gravity at P is now computed in two different ways depending on the input height of P.
       1. input height h>0: P is considered according to case [a] in sect.4, assuming the input height h is the height of the point considered. Accordingly, gravity g\* at the point considered is calculated

analogously to form. (8) reducing gravity gB\*B considered using ground density ρ=2.67g/cm3

from the fictitious geoid, cf. sect.4, to the point

g\* = gB\*B - 0.3086h + 0.1119h (10)

* + - 1. input height h<0: P is considered according to case [b], assuming -h is the depth of the sea. Accordingly, gravity g\* at the point considered is computed analogously to (9)

g\* = gB\*B - 0.1119(-h) + 0.0482(-h) (11)

Obviously, to make sense the Bouguer anomalies of the data points should refer to ρ=2.67.

* 1. **Modifications.** For the sake of documentation the GeoGrid program has been used unchanged, however, a few minor modifications would have simplified significantly the following procedure of gravity interpolation.

As mentioned before ρ=2.00 is used for leveling in Denmark. Consequently, the Bouguer anomalies of the data points should refer to the same value. Given anomaly values ΔgBB referring to ρ=2.67 are easily transformed into corresponding values *ΔgB* referring to ρ=2.00. Regarding a data point P, case [a] or [b], it is immediately seen from formulas corresponding to (7), (8), and (9)

[a]: *ΔgB* = ΔgBB + (0.1119-0.0838)h (12)

The same formula goes for case [b] replacing h in the formula above by -d.

Now, what is happening, if GeoGrid is applying a data list of Bouguer anomalies (ρ=2.00)? Let *ΔgB\** be the resulting interpolated Bouguer anomaly of the point P and *g\** the corresponding outcome from GeoGrid. Since the data list is referring to ρ=2.00 GeoGrid should have used the same value in the computation of *g\**. Taking this into account (modification 1) it is seen from (10) and (11) that no matter of the sign of the input height h the consistent gravity value at the point considered by GeoGrid is

*g\*\** = *g\** + (0.0838-0.1119)h (13)

Below, we are giving gravity *gP\** (in mgal) consistently interpolated based on ρ=2.00 at the point P depending on the different cases in sect.4. It is assumed the GeoGrid input height of P is the height h of P, except in case [b], where the input height -d is assumed. As is evident from above

[a], [b]: *gP\** = *g\*\**

In the other cases further steps are needed, since gravity *g\*\** has to be reduced from the point considered by GeoGrid to the point P (modification 2). Below we are continuing the example in sect.3, i.e. case [e], t1>0.

□ Example (cont.): Since the height of point P is negative, *g\*\** is gravity at the point considered, i.e. the point Po, assuming -h is the depth of the sea, cf. 3.b. in sect.5.1. Hence, interpolated gravity *gP\** at P is obtained removing the fictitious sea water plate from P to Po, lowering Po to P through free air, and adding the plates of soil and water from P to P1 and P1 to Po, respectively. Hence

[e], t1>0: *gP\** = *g\*\** - 0.0432(-h) + 0.3086(-h) - 0.0838t1 - 0.0432d □

Similarly, we find

[e], t1<0: *gP\** = *g\*\** - 0.0432(-h) + 0.3086(-h) - 0.0838(-t1) + 0.0432(-t1) - 0.0432(-h) [c]: *gP\** = *g\*\** - 0.0838(h+d) + 0.0432d

[d]: *gP\** = *g\*\** - 0.0838ho

## The computation of mean gravity g .

Mean gravity is needed for the transformation of geopotential numbers into orthometric heights, or vice versa, cf. (3). It is also needed for the computation of orthometric corrections, cf. (6). According to (4) mean

gravity g P

corresponding to the point P is determined from integration of gravity g along the plumb line

from the geoid to P. However, this gravity is normally unknown. The Helmert approach to solve the problem is to replace the masses along the plumb line by corresponding Bouguer plates. By this, gravity between the geoid and the point P becomes a piecewise linear function of distance in accordance with the different plates. Thus, mean gravity along the section of the plumb line cut out by a given plate, is easily found from the arithmetic mean of gravity at the section’s endpoints.

Corresponding to the different cases in sect.4 we are giving below mean gravity

g P (in mgal) based on

ρ=2.00 of the point P, HP is the orthometric height of P. To make the procedure more comprehensible we are continuing the example in sect.3.

□ Example (cont.): Splitting up the integration according to the plates of soil and sea water between P and Po

mean gravity g P

t1

can be written

g P

HP

= -(I1 + I2)/HP

Here I1 =  g(s)ds

0

and I2 =

 g(s)ds . As is seen from the example g(s) is a piecewise linear function of s in

t1

accordance with the plates. Thus, I1=½(gP+g1)t1, I2=½(g1+go)d, hence

[e], t >0:

g =  ½(g P  g1 )t1  ½(g1  go )d

1 P

H

P

Gravity gP is often found by interpolation, whereas go and g1 are given in sect.3. □

Similarly, mean gravity corresponding to P in all other cases is given by

[e], t1<0:

[a]:

1. :

g P = gP + ½(0.3086 - 2·0.0432)Hp

g P = gP + ½(0.3086 - 2·0.0838)Hp

g P = gP + ½·0.3086Hp

1. :

g = ½(g o  g1 )(H P  ho )  ½(g1  g P )ho

P HP

where go is gravity at the geoid below P and g1 is corresponding to the ground , i.e.

go = g1 + (0.3086 - 2·0.0838)(HP - ho) g1 = gP + 0.3086ho

1. **Dataflow.** The diagram below is illustrating the entire dataflow during gravity interpolation and leveling adjustment. The dot-and-dash lines are irrelevant, since geopotential differences have not been used. The denotation is in accordance with previous sections.

transform.

**GeoGrid**

(mod.1)

(mod.1)

(mod.2)

gravity *g\**

[c]-[e]

interpolated case [a]

interpol. points and input heights

Bouguer anomalies

*ΔgB* (2.00)

mod. gravity *g\*\**

datapoints: Bouguer ano- malies ΔgB (2.67)

.

.

.



orthom. height diff.

adj. geopot. numbers

adj. Helmert heights

orthom. corrections



geopotential differences

lev. height diff.

final gravity *gP\**

mean gravity g P

# Appendix 2

1. **Stability investigation in the Helsingør region**

According to the set up in table 1 we have to look for a stable subsoil benchmark leveled in 1980 and 1992. Since most of the subsoil points have been omitted in the leveling from 1992 the number of candidates can be narrowed down to the following: Kvistgård (G.I.1646, G.I.1647, G.I.1648), Hamlets Grav (G.I.1605, G.I.1606, G.I.1607), and G.M.1341. The point last-mentioned is unsuitable for connection, it is located on a bastion of the Kronborg Castle and a subsidence of about 35mm relative to Hamlets Grav has taken place from 1940 to 1992. Due to numerous surveying campaigns in the area precise leveling has been conducted frequently: 1898 (First Precise Leveling), 1908, 1939, 1940, 1941, 1942, 1943 (Second Precise Leveling), 1980, 1983, and 1992 (Third Precise Leveling). However, in order to evaluate stability between and within the groups Hamlets Grav and Kvistgård, cf. fig. 4, only the levelings from 1941 on are relevant, simply because the groups did not exist before 1940 and 1941, respectively. The data sources applied are indicated in table A1, where the pages are referring to computation volumes of G.I. For the sake of completeness we also give the references of the oldest levelings: 1898(#DK\_niDprs), 1908(p.142 ff.), 1939(p.2058 ff.).

* 1. **Leveling within the groups of Hamlets Grav and Kvistgård.** In table A1 we have listed all measurements available. The results recorded are means of 4 to 9 single runs with sight lengths of about 35m.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Hamlets Grav: |  | 1940 | 1941 | 1942 | 1943 | 1980 | 1983 | 1992 | |
|  | G.I.1605 |  |  |  |  |  |  |  | |
|  |  | -0.55719 | -0.55692 | -0.55673 | -0.55652 | -0.55799 | -0.55809 | -0.55776 | |
|  | G.I.1606 |  |  |  |  |  |  |  | |
|  |  | -0.89963 | -0.89914 | -0.89946 | -0.89966 | -0.89785 | -0.89804 | -0.89827 | |
|  | G.I.1607 | ----------- | ----------- | ----------- | ----------- | ----------- | ----------- | ----------- | |
|  |  | -1.45682 | -1.45606 | -1.45619 | -1.45618 | -1.45584 | -1.45613 | -1.45603 | |
| source: p.2077 ff. p.2186 ff p.2366 ff p.7709 ff #DK\_niDniv #DK\_niDniv #DK\_niDprs  -------------------------------------------------------------------------------------------------------------------------------------------- | | | | | | | | | |
| Kvistgård: |  | 1941 | | 1942 | 1943 | 1980 | 1983 | | 1992 |
|  | G.I.1646 |  | |  |  |  |  | |  |
|  |  | -0.96802 | | -0.96806 | -0.96804 | -0.96890 | -0.96902 | | -0.96894 |
|  | G.I.1647 |  | |  |  |  |  | |  |
|  |  | -0.75873 | | -0.75860 | -0.75872 | -0.75801 | -0.75786 | | -0.75654 |
|  | G.I.1648 | ----------- | | ----------- | ----------- | ----------- | ----------- | | ----------- |
|  |  | -1.72675 | | -1.72666 | -1.72676 | -1.72691 | -1.72688 | | -1.72548 |

source: #DK\_niDprs #DK\_niDprs #DK\_niDprs #DK\_niDniv #DK\_niDniv #DK\_niDprs table A1: Repeated levelings within the groups

Considering the group Hamlets Grav we can conclude that G.I.1605 and G.I.1607 can be considered mutually stable from 1941 to 1992, whereas G.I.1606 has subsided about 1½mm during the years from 1943 to 1980, hereafter the point seems stable. That means any one of the three benchmarks could be used for the connection 1980/1992. As regards the Kvistgård group we notice mutual stability of G.I.1646 and G.I.1647 from 1980 on, whereas G.I.1648 has raised about 1½mm (according to the field books this is probably caused by some construction work close to the point).

* 1. **Levelling between the groups.** Below, we are giving the levelings available from Kvistgård (G.I.1647) to Hamlets Grav (G.I.1607), which are including the old subsoil benchmark G.M.1337 from the First Precise Leveling. The results recorded are rounded measured height differences summed up along the shortest route connecting the groups. The same data sources as above have been used.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1940 | 1941 | 1942 | 1943 | 1980 | 1983 | 1992 |
| G.I.1647 |  |  |  |  |  |  |  |
| 4.5km |  | -4.513 | -4.516 | -4.515 | -4.517 | -4.516 | - |
| G.M.1337 |  |  |  |  |  |  |  |
| 4.5km | -16.278 | -16.276 | -16.279 | -16.277 | -16.267 | -16.272 | - |
| G.I.1607 |  | ---------- | ---------- | ----------- | ---------- | ---------- |  |
| -20.790 -20.794 -20.792 -20.784 | | | | | | -20.788 | -20.789 |

table A2: Repeated levelings between the groups

From the table we can conclude that G.I.1647 and G.M.1337 seem mutually stable from the forties up to the eighties, whereas in 1980 there is an apparent raise of G.I.1607 of about 10mm relative to G.M.1337. Since this could not be explained neither by a gross leveling error nor by postglacial uplift a new leveling was carried out in 1983, now indicating a subsidence of about 5mm since 1980. The validity of these contradicting results seems rather unlikely. However, since the result from 1983 is confirmed in 1992 we have decided to ignore the leveling from 1980 as much as possible. This is excluding the Kvistgård benchmarks for the connection 1980/1992, thus, the benchmark G.I.1607, which is directly entering the leveling line, has been selected as connection point. As is seen from the table there might be a raise of a few

millimeters of G.I.1607 relative to G.I.1647 during the period from the forties up to the nineties. This is in good agreement with the postglacial land uplift according to Ekman (1996).

The reason for the suspicious deviation of the height difference in 1980 from G.M.1337 and G.I.1607 can hardly be found today, but perhaps it should be mentioned that most of the leveling sections in 1980 were measured by three single runs according to the field book GA.I, journal bind 102. That means systematic errors might not be fully removed from the means, which have been used in the computation of the height difference in question.

# Gravity along the Link.

* 1. **Gravity and Bouger anomalies of the new gravity points, ρ=2.00.** The gravity profile of the Link has been measured relative to the KMS gravity station 120 in the beginning of April 2000 by two LaCoste Romberg gravimeters, G867 and G466. The location of the new points can be seen from the bold points in fig.7. Measured gravity gP and corresponding Bouguer anomalies ΔgB computed from the formulas in app.1, sect.4, are given below. Normal gravity γo has been computed as mentioned in app.1, sect.4. The leveled heights h of the points in the tunnel are including an offset of 65 cm, since gravity was measured at the bottom of tunnel. The depth d of the sea has been estimated roughly from a marine map.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| point no. | loc. | gP | h | d | ΔgB |
| 4078/432 661 | EastBridge | 981 531.40 mgal | 26.84 m | 2 m | -15.76 mgal |
| 4078/430 661 | East Bridge | 521.17 | 61.71 | 7 | -15.50 |
| 4078/411 061 | West Bridge | 524.65 | 53.46 | 7 | -15.36 |
| 4078/301 119 | Peberholm | 539.63 | 12.34 | - | -15.14 |
| 4078/300 501 | Tunnel | 543.93 | -3.70 | 3 | -15.90 |
| 4078/919 | Tunnel | 547.19 | -19.59 | 9 | -16.24 |

table A3: Measured gravity and Bouguer anomalies (ρ=2.00) of the gravity profile of the Link

* 1. **Interpolated gravity *gP\**, ρ=2.00.** The gravity values in table A4 have been computed according to app.1, sect 5.2. Bold point numbers are referring to stable points kept in the KMS point database. The last column is indicating points, which have been measured by one national team only.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | point P | h | d | *gP\** |
| Bridge | **4078/500 503** | 19.48 m | 2 m | 981533.88 mgal |
|  | **4078/500 502** | 21.99 | 2 | 981532.95 Sw |
|  | **4078/500 501** | 22.00 | 2 | 981532.97 |
|  | **4078/500 501.1** | 22.00 | 2 | 981532.97 DK |
|  | 4078/432 861 | 23.86 | 2 | 981532.33 Sw |
|  | 4078/432 661 | 26.84 | 2 | 981531.40 |
|  | 4078/432 461 | 30.34 | 2 | 981530.36 |
|  | 4078/432 261 | 33.81 | 2 | 981529.34 |
|  | 4078/432 061 | 37.35 | 3 | 981528.24 DK |
|  | 4078/431 961 | 37.40 | 3 | 981528.23 Sw |
|  | 4078/431 861 | 40.82 | 3 | 981527.22 |
|  | 4078/431 661 | 44.26 | 4 | 981526.18 |
|  | 4078/431 461 | 47.76 | 5 | 981525.12 |
|  | 4078/431 261 | 51.22 | 5 | 981524.18 |
|  | 4078/431 061 | 54.75 | 6 | 981523.16 |
|  | 4078/430 861 | 58.22 | 6 | 981522.20 |
|  | 4078/430 661 | 61.71 | 7 | 981521.17 |
|  | 4078/430 461 | 64.78 | 7 | 981520.28 |
|  | 4078/430 261 | 67.07 | 7 | 981519.57 |
| (pylon) | **4078/400 506** | 68.88 | 7 | 981518.94 |
| (pylon) | **4078/400 502** | 68.91 | 7 | 981518.71 |
|  | 4078/410 261 | 67.13 | 7 | 981519.15 |
|  | 4078/410 461 | 64.78 | 7 | 981519.77 |
|  | 4078/410 661 | 61.70 | 7 | 981521.01 |
|  | 4078/410 861 | 57.82 | 7 | 981522.95 |
|  | 4078/411 061 | 53.46 | 7 | 981524.65 |
|  | 4078/411 261 | 49.03 | 7 | 981526.02 |
|  | 4078/411 461 | 44.66 | 6 | 981527.42 |
|  | 4078/411 661 | 40.25 | 6 | 981528.83 |
|  | 4078/411 861 | 35.88 | 5 | 981530.34 |
|  | 4078/412 061 | 31.48 | 5 | 981531.82 |
|  | 4078/412 261 | 27.74 | 5 | 981533.13 |
|  | 4078/412 461 | 23.94 | 5 | 981534.44 |
|  | 4078/413 261 | 20.28 | 4 | 981535.78 Sw |
| Bridge | **4078/300 511** | 15.63 | 4 | 981537.51 |
| Peberholm | 4078/301 119 | 12.34 | - | 981539.63 |
|  | 4078/301 047 | 11.40 | - | 981539.95 |
|  | 4078/301 011 | 11.38 | - | 981540.01 |
| Peberholm | 4078/300 975 | 9.78 | - | 981540.48 |
| Tunnel | **4078/300 502** | -0.64 | 3 | 981543.29 |
|  | **4078/300 501** | -3.05 | 3 | 981543.85 (to be continued) |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| (continued) |  | | | | |
|  |  | 4078/1 409 | -9.56 | 3 | 981544.93 |
|  |  | 4078/1 919 | -14.61 | 5 | 981545.91 |
|  |  | 4078/1 719 | -16.30 | 5 | 981546.31 |
|  |  | 4078/1 519 | -17.31 | 9 | 981546.77 |
|  |  | 4078/1 319 | -18.38 | 9 | 981547.08 |
|  |  | 4078/1 119 | -19.44 | 9 | 981547.47 |
|  |  | 4078/919 | -18.94 | 9 | 981547.09 |
|  |  | 4078/719 | -17.90 | 9 | 981547.16 |
|  |  | 4078/519 | -16.86 | 9 | 981546.96 |
|  |  | 4078/319 | -15.50 | 5 | 981546.77 |
|  |  | 4078/119 | -10.78 | 3 | 981546.13 |
|  |  | **4078/100 502** | -4.61 | 2 | 981545.30 |
|  | Tunnel | **4078/100 501** | -1.80 | 2 | 981544.89 |

table A4: Interpolated gravity (ρ=2.00) along the Link

# ●●●

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Hamlets Grav - Pålsjø Cliff

# Double runs of the Oeresund Loop

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| G.I.1607  K -06-09006 | K -06-09006  K -06-09034 | 555  430 | -18.40051  0.99555 | 022\*1\*5511 022\*2\*5505  022\*2\*5505 022\*1\*5512 | 1052  886 | -2.05822  3.24222 |
| K -06-09034 | K -06-00087 | 344 | -2.91636 | 022\*1\*5512 022\*2\*4501 | 685 | 0.32640 |
| K -06-00087 | K -06-00053 | 518 | -0.46586 | 022\*2\*4501 022\*1\*4505 | 958 | -3.45540 |
| K -06-00087 | K -06-00053 | 534 | -0.46664 | 022\*1\*4505 022\*1\*4506 | 1170 | 3.48181 |
| K -06-00053 | K -06-09168 | 217 | 2.55088 | 022\*1\*4506 022\*1\*4507 | 1248 | -2.04387 |
| K -06-09168 | K -06-09008 | 227 | 4.57693 | 022\*1\*4507 022\*1\*4508 | 924 | -1.22395 |
| K -06-09008 | K -06-09170 | 22 | 21.7468 | 022\*1\*4508 022\*2\*4504 | 1272 | -0.02258 |
| K -06-09170 | 032\*2\*3116 | 4800 | -0.5903 | 022\*2\*4504 022\*1\*4509 | 816 | -1.29970 |
| Pålsjø Cliff - | East Bridge |  |  | 022\*1\*4509 022\*1280\*0764 | 162 | 1.40626 |
| 032\*2\*3116 | 032\*2\*3102 | 476 | -26.42334 | 022\*1280\*0764 022\*1280\*0959 | 455 | 0.21849 |
| 032\*2\*3102 | 032\*1283\*0713 | 197 | 2.57716 | 022\*1280\*0959 022\*1\*3506 | 419 | 0.31138 |
| 032\*1283\*0713 | 032\*1283\*0953 | 880 | -2.74134 | 022\*1\*3506 022\*1280\*0958 | 872 | -1.12392 |
| 032\*1283\*0953 | 032\*1283\*0922 | 778 | -0.80837 | 022\*1280\*0958 022\*1\*3507 | 859 | 3.02548 |
| 032\*1283\*0922 | 032\*1283\*0703 | 361 | 4.80158 | 022\*1\*3507 022\*1280\*0080 | 300 | 0.64929 |
| 032\*1283\*0703 | 032\*1283\*1032 | 250 | -0.47496 | 022\*1280\*0080 022\*1\*3508 | 336 | -0.12420 |
| 032\*1283\*1032 | 032\*1\*3124 | 196 | 25.30183 | 022\*1\*3508 022\*1280\*0288 | 379 | 0.63550 |
| 032\*1\*3124 | 032\*1\*3119 | 295 | -0.23249 | 022\*1280\*0288 022\*1\*3509 | 265 | -0.81723 |
| 032\*1\*3119 | 032\*1\*3120 | 1189 | -7.57831 | 022\*1\*3509 022\*1280\*0141 | 401 | -1.10018 |
| 032\*1\*3120 | 032\*1\*3121 | 965 | -16.81553 | 022\*1280\*0141 022\*1\*3510 | 431 | 0.66180 |
| 032\*1\*3121 | 032\*9999\*3121 | 429 | -0.36191 | 022\*1\*3510 022\*1280\*0142 | 244 | 2.50207 |
| 032\*9999\*3121 | 032\*1\*3123 | 1418 | -0.26218 | 022\*1280\*0142 022\*1\*3511 | 460 | -0.12100 |
| 032\*1\*3123 | 032\*2\*2101 | 1050 | 1.60767 | 022\*1\*3511 022\*1280\*0255 | 164 | 1.26987 |
| 032\*2\*2101 | 032\*1\*2104 | 1287 | -3.72564 | 022\*1280\*0255 022\*1\*3401 | 591 | 0.45717 |
| 032\*1\*2104 | 032\*1\*2105 | 941 | 0.31725 | 022\*1\*3401 022\*1280\*0249 | 385 | 2.45994 |
| 032\*1\*2105 | 032\*1\*2106 | 830 | -2.86912 | 022\*1280\*0249 022\*1\*3402 | 487 | 0.01928 |
| 032\*1\*2106 | 032\*1\*2107 | 1167 | 19.63731 | 022\*1\*3402 022\*1280\*0465 | 643 | 2.87132 |
| 032\*1\*2107 | 032\*1\*2206 | 624 | -2.24019 | 022\*1280\*0465 022\*1\*2425 | 464 | 1.85279 |
| 032\*1\*2206 | 032\*1\*1204 | 1569 | -1.47465 | 022\*1\*2425 022\*1280\*0956 | 435 | -2.65869 |
| 032\*1\*1204 | 032\*1\*1210 | 1047 | 2.94908 | 022\*1280\*0956 022\*2\*2414 | 642 | -1.37452 |
| 032\*1\*1210 | 032\*1\*1211 | 1432 | 14.73561 | 022\*2\*2414 022\*1280\*0477 | 525 | 0.40207 |
| 032\*1\*1211 | 032\*1\*1212 | 1103 | 2.72038 | 022\*1280\*0477 022\*1280\*0914 | 193 | -0.01146 |
| 032\*1\*1212 | 032\*1\*1213 | 523 | 6.02802 | 022\*1280\*0914 022\*1\*2422 | 388 | 4.15367 |
| 032\*1\*1213 | 032\*1\*1309 | 1009 | 7.69969 | 022\*1\*2422 022\*1\*2421 | 675 | -0.64702 |
| 032\*1\*1309 | 032\*11\*1317 | 576 | -9.98954 | 022\*1\*2421 022\*1\*2420 | 813 | 9.48434 |
| 032\*11\*1317 | 032\*1\*1311 | 1687 | 8.36616 | 022\*1\*2420 022\*1\*2419 | 556 | -2.03922 |
| 032\*1\*1311 | 032\*1\*1316 | 660 | 1.66891 | 022\*1\*2419 022\*1\*2418 | 913 | -1.84510 |
| 032\*1\*1316 | 032\*11\*0309 | 1081 | 9.63501 | 022\*1\*2418 022\*1\*2417 | 1286 | -3.84499 |
| 032\*11\*0309 | 032\*1\*0205 | 1084 | -5.36118 | 022\*1\*2417 022\*1\*2423 | 939 | -1.86249 |
| 032\*1\*0205 | 032\*1\*0206 | 1048 | -10.48983 | 022\*1\*2423 022\*9999\*2423 | 492 | -2.89425 |
| 032\*1\*0206 | 032\*11\*0210 | 1268 | -16.94041 | 022\*9999\*2423 022\*46\*200004 | 756 | 2.04942 |
| 032\*11\*0210 | 032\*1\*0209 | 1155 | -17.83328 | 022\*46\*200004 022\*1\*2311 | 857 | -1.78011 |
| 032\*1\*0209 | 032\*1\*0207 | 592 | 0.01595 | 022\*1\*2311 022\*1\*2310 | 818 | 0.62461 |
| 032\*1\*0207 | 022\*1\*9204 | 1236 | -2.78429 | 022\*1\*2310 022\*46\*200003 | 648 | -0.70353 |
| 022\*1\*9204 | 022\*1\*9205 | 1236 | -5.30230 | 022\*46\*200003 022\*1\*2309 | 367 | -3.60825 |
| 022\*1\*9205 | 022\*1\*9309 | 1334 | -1.55838 | 022\*1\*2309 022\*1\*2308 | 916 | 0.21854 |
| 022\*1\*9309 | 022\*1\*9310 | 1031 | 0.71776 | 022\*1\*2308 022\*46\*200001 | 609 | -0.38980 |
| 022\*1\*9310 | 022\*9999\*9304 | 1531 | 0.83602 | 022\*46\*200001 4078/500 503 | 978 | 9.96653 |
| 022\*9999\*9304 | 022\*1\*9312 | 1294 | -1.41624 | East Bridge - High Bridge |  |  |
| 022\*1\*9312 | 022\*1\*9313 | 898 | 5.43764 | 4078/500 503 4078/500 501 | 225 | 2.52102 |
| 022\*1\*9313 | 022\*1\*8303 | 997 | -5.72160 | 4078/500 503 4078/500 501.1 | 274 | 2.51802 |
| 022\*1\*8303 | 022\*1\*8304 | 813 | 5.73844 | 4078/500 502 4078/500 501 | 81 | 0.00201 |
| 022\*1\*8304 | 022\*1\*8305 | 1318 | -4.60347 | 4078/500 501 4078/432 661 | 389 | 4.83744 |
| 022\*1\*8305 | 022\*1\*8306 | 1278 | 0.59006 | 4078/500 501.1 4078/432 661 | 394 | 4.84160 |
| 022\*1\*8306 | 022\*1\*8409 | 790 | -0.31506 | 4078/432 661 4078/432 461 | 281 | 3.50224 |
| 022\*1\*8409 | 022\*1\*7409 | 1887 | 0.09927 | 4078/432 661 4078/432 461 | 279 | 3.50303 |
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| 022\*1\*7408 | 022\*1\*7303 | 1111 | 0.40551 | 4078/432 461 4078/432 261 | 278 | 3.46932 |
| 022\*1\*7303 | 022\*1\*7301 | 1048 | -0.17979 | 4078/432 261 4078/432 061 | 277 | 3.53847 |
| 022\*1\*7301 | 022\*9999\*7410 | 714 | 7.87950 | 4078/432 261 4078/432 061 | 275 | 3.53928 |
| 022\*9999\*7410 | 022\*1\*7403 | 1368 | -4.45244 | 4078/432 061 4078/431 861 | 282 | 3.46901 |
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| 022\*1\*6405 | 022\*11\*6407 | 1253 | -2.81875 | 4078/431 661 4078/431 461 | 280 | 3.50370 |
| 022\*11\*6407 | 022\*1\*6517 | 989 | -5.87114 | 4078/431 461 4078/431 261 | 281 | 3.45594 |
| 022\*11\*6407 | 022\*1\*6517 | 987 | -5.87151 | 4078/431 461 4078/431 261 | 281 | 3.45666 |
| 022\*1\*6517 | 022\*1\*6518 | 1298 | 2.72412 | 4078/431 261 4078/431 061 | 283 | 3.52902 |
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| 022\*1\*6516 | 022\*1\*5507 | 1266 | 4.07845 | 4078/430 861 4078/430 661 | 281 | 3.48961 |
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| 022\*1\*5508 | 022\*1\*5509 | 1204 | -1.55751 | 4078/430 661 4078/430 461 | 279 | 3.06866 |
| 022\*1\*5509 | 022\*1\*5510 | 1247 | 0.17462 | 4078/430 461 4078/430 261 | 276 | 2.29430 |
| 022\*1\*5510 | 022\*1\*5511 | 1228 | 0.83019 | 4078/500 503 4078/500 502 | 227 | 2.51847 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 4078/500 | 503 | 4078/500 | 501 | 224 | 2.52099 | 4078/410 | | 861 | 4078/411 | | 061 | 282 | -4.35910 |
| 4078/500 | 503 | 4078/500 | 501.1 | 224 | 2.51856 | 4078/411 | | 061 | 4078/411 | | 261 | 283 | -4.42647 |
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| 4078/500 | 501.1 | 4078/432 | 861 | 148 | 1.86723 | 4078/411 | | 061 | 4078/411 | | 461 | 564 | -8.79287 |
| 4078/432 | 861 | 4078/432 | 661 | 242 | 2.97255 | 4078/411 | | 261 | 4078/411 | | 461 | 282 | -4.36598 |
| 4078/432 | 861 | 4078/432 | 661 | 253 | 2.97289 | 4078/411 | | 261 | 4078/411 | | 461 | 282 | -4.36538 |
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| 4078/432 | 261 | 4078/431 | 961 | 285 | 3.59686 | 4078/411 | | 461 | 4078/411 | | 861 | 563 | -8.78378 |
| 4078/432 | 261 | 4078/431 | 961 | 285 | 3.59670 | 4078/411 | | 661 | 4078/411 | | 861 | 280 | -4.37374 |
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| 4078/431 | 661 | 4078/431 | 461 | 282 | 3.50300 | 4078/412 | | 061 | 4078/412 | | 261 | 242 | -3.73727 |
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| 4078/431 | 461 | 4078/431 | 261 | 282 | 3.45670 | 4078/412 | | 261 | 4078/412 | | 461 | 245 | -3.80009 |
| 4078/431 | 461 | 4078/431 | 261 | 282 | 3.45619 | 4078/412 | | 261 | 4078/412 | | 461 | 245 | -3.79952 |
| 4078/431 | 261 | 4078/431 | 061 | 284 | 3.52845 | 4078/412 | | 261 | 4078/413 | | 261 | 479 | -7.46441 |
| 4078/431 | 261 | 4078/431 | 061 | 283 | 3.52812 | 4078/412 | | 261 | 4078/413 | | 261 | 479 | -7.46470 |
| 4078/431 | 261 | 4078/430 | 861 | 564 | 6.99879 | 4078/412 | | 461 | 4078/413 | | 261 | 234 | -3.66453 |
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| 4078/430 | 861 | 4078/430 | 661 | 282 | 3.48938 | 4078/413 | | 261 | 4078/300 | | 511 | 347 | -4.65112 |
| 4078/430  4078/430 | 861  861 | 4078/430  4078/430 | 661  461 | 282  563 | 3.48955  6.55795 | 4078/413 261 4078/300  Peberholm - Tunnel | | | | | 511 | 349 | -4.65219 |
| 4078/430 | 661 | 4078/430 | 461 | 282 | 3.06779 | 4078/300 | | 511 | 4078/301 | | 119 | 482 | -3.28364 |
| 4078/430 | 461 | 4078/430 | 261 | 353 | 2.29429 | 4078/301 | | 119 | 4078/301 | | 083 | 478 | -0.96298 |
| 4078/430 461 4078/430 261  High Bridge - West Bridge | | | | 280 | 2.29449 | 4078/301  4078/301 | | 119  083 | 4078/301  4078/301 | | 083  047 | 479  481 | -0.96315  0.01445 |
| 4078/430 | 261 | 4078/400 | 506 | 306 | 1.80896 | 4078/301 | | 083 | 4078/301 | | 047 | 481 | 0.01444 |
| 4078/430 | 261 | 4078/400 | 506 | 303 | 1.80869 | 4078/301 | | 047 | 4078/301 | | 011 | 478 | -0.01556 |
| 4078/400 | 506 | 4078/400 | 502 | 529 | 0.02962 | 4078/301 | | 047 | 4078/301 | | 011 | 482 | -0.01567 |
| 4078/400 | 506 | 4078/400 | 502 | 490 | 0.02833 | 4078/301 | | 011 | 4078/300 | | 975 | 481 | -1.60287 |
| 4078/400 | 502 | 4078/410 | 261 | 434 | -1.77911 | 4078/301 | | 011 | 4078/300 | | 975 | 479 | -1.60311 |
| 4078/400 | 502 | 4078/410 | 261 | 301 | -1.77923 | 4078/300 | | 975 | 4078/300 | | 502 | 669 | -10.41639 |
| 4078/430 | 261 | 4078/400 | 506 | 307 | 1.80986 | 4078/300 | | 975 | 4078/300 | | 502 | 668 | -10.41640 |
| 4078/430 | 261 | 4078/400 | 506 | 306 | 1.80885 | 4078/300 | | 502 | 4078/300 | | 501 | 92 | -2.41440 |
| 4078/430 | 261 | 4078/400 | 506 | 307 | 1.81112 | 4078/300 | | 502 | 4078/300 | | 501 | 96 | -2.41390 |
| 4078/400 | 506 | 4078/400 | 502 | 495 | 0.02905 | 4078/300 | | 511 | 4078/301 | | 119 | 482 | -3.28277 |
| 4078/400 | 502 | 4078/410 | 261 | 304 | -1.77968 | 4078/300 | | 511 | 4078/301 | | 119 | 484 | -3.28357 |
| 4078/400 | 502 | 4078/410 | 261 | 304 | -1.78008 | 4078/301 | | 119 | 4078/301 | | 083 | 481 | -0.96399 |
| 4078/400 | 502 | 4078/410 | 261 | 305 | -1.77994 | 4078/301 | | 119 | 4078/301 | | 083 | 482 | -0.96373 |
| 4078/400 | 502 | 4078/410 | 261 | 304 | -1.77933 | 4078/301 | | 083 | 4078/301 | | 047 | 485 | 0.01408 |
| 4078/400 502 4078/410  West Bridge - Peberholm | | | 261 | 304 | -1.77955 | 4078/301  4078/301 | | 083  083 | 4078/301  4078/301 | | 047  047 | 482  481 | 0.01438  0.01445 |
| 4078/410 | 261 | 4078/410 | 461 | 278 | -2.35130 | 4078/301 | | 047 | 4078/301 | | 011 | 493 | -0.01670 |
| 4078/410 | 261 | 4078/410 | 461 | 278 | -2.35010 | 4078/301 | | 047 | 4078/301 | | 011 | 481 | -0.01630 |
| 4078/410 | 461 | 4078/410 | 661 | 277 | -3.07664 | 4078/301 | | 047 | 4078/301 | | 011 | 482 | -0.01674 |
| 4078/410 | 661 | 4078/410 | 861 | 279 | -3.88796 | 4078/301 | | 011 | 4078/300 | | 975 | 484 | -1.60312 |
| 4078/410 | 661 | 4078/410 | 861 | 281 | -3.88824 | 4078/301 | | 011 | 4078/300 | | 975 | 482 | -1.60309 |
| 4078/410 | 861 | 4078/411 | 061 | 280 | -4.35990 | 4078/300 | | 975 | 4078/300 | | 502 | 676 | -10.41739 |
| 4078/410 | 861 | 4078/411 | 061 | 281 | -4.35970 | 4078/300 | | 975 | 4078/300 | | 502 | 668 | -10.41721 |
| 4078/411 | 061 | 4078/411 | 261 | 282 | -4.42618 | 4078/300 | | 502 | 4078/300 | | 501 | 99 | -2.41405 |
| 4078/411 | 061 | 4078/411 | 261 | 283 | -4.42741 | 4078/300 | | 502 | 4078/300 | | 501 | 94 | -2.41337 |
| 4078/411 | 261 | 4078/411 | 461 | 281 | -4.36659 | 4078/300 | | 502 | 4078/300 | | 501 | 95 | -2.41375 |
| 4078/411 | 261 | 4078/411 | 461 | 279 | -4.36644 | 4078/300 | | 502 | 4078/300 | | 501 | 96 | -2.41406 |
| 4078/411  4078/411 | 461  461 | 4078/411  4078/411 | 661  661 | 283  280 | -4.40889  -4.40904 | 4078/300  Tunnel - | | 502 4078/300  Copenhagen | | | 501 | 94 | -2.41392 |
| 4078/411 | 661 | 4078/411 | 861 | 283 | -4.37433 | 4078/300 | | 501 | 4078/1 | 409 | | 331 | -6.50129 |
| 4078/411 | 661 | 4078/411 | 861 | 280 | -4.37394 | 4078/300 | | 501 | 4078/1 | 409 | | 272 | -6.50114 |
| 4078/411 | 861 | 4078/412 | 061 | 282 | -4.39739 | 4078/1 | 409 | | 4078/1 | 919 | | 356 | -5.05040 |
| 4078/411 | 861 | 4078/412 | 061 | 279 | -4.39711 | 4078/1 | 409 | | 4078/1 | 919 | | 357 | -5.05012 |
| 4078/412 | 061 | 4078/412 | 261 | 244 | -3.73762 | 4078/1 | 919 | | 4078/1 | 719 | | 350 | -1.68694 |
| 4078/412 | 061 | 4078/412 | 261 | 239 | -3.73690 | 4078/1 | 919 | | 4078/1 | 719 | | 351 | -1.68650 |
| 4078/412 | 261 | 4078/412 | 461 | 245 | -3.80004 | 4078/1 | 719 | | 4078/1 | 519 | | 352 | -1.01608 |
| 4078/412 | 261 | 4078/412 | 461 | 245 | -3.80019 | 4078/1 | 719 | | 4078/1 | 519 | | 352 | -1.01654 |
| 4078/412 | 461 | 4078/300 | 511 | 581 | -8.31633 | 4078/1 | 519 | | 4078/1 | 319 | | 348 | -1.07300 |
| 4078/410 | 261 | 4078/410 | 461 | 280 | -2.35134 | 4078/1 | 519 | | 4078/1 | 319 | | 349 | -1.07318 |
| 4078/410 | 261 | 4078/410 | 461 | 280 | -2.34970 | 4078/1 | 319 | | 4078/1 | 119 | | 352 | -1.06228 |
| 4078/410 | 261 | 4078/410 | 661 | 564 | -5.42706 | 4078/1 | 319 | | 4078/1 | 119 | | 351 | -1.06185 |
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| 4078/410 | 461 | 4078/410 | 661 | 282 | -3.07612 | 4078/1 119 | | | 4078/919 | | 350 | | 0.50024 |
| 4078/410 | 461 | 4078/410 | 661 | 282 | -3.07555 | 4078/919 | | | 4078/719 | | 348 | | 1.04203 |
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| 4078/410 | 661 | 4078/411 | 061 | 563 | -8.24807 | 4078/719 | | | 4078/519 | | 349 | | 1.04400 |
| 4078/410 | 861 | 4078/411 | 061 | 282 | -4.35942 | 4078/519 | | | 4078/319 | | 348 | | 1.35837 |

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| 4078/519 | 4078/319 | 351 | 1.35806 | K -01-06429 | K -01-08057 | 290 | -0.64472 |
| 4078/319 | 4078/119 | 349 | 4.71790 | K -01-08057 | K -01-08175 | 225 | 0.49246 |
| 4078/319 | 4078/119 | 352 | 4.71824 | K -01-08175 | K -01-06400 | 150 | 0.10273 |
| 4078/119 | 4078/100 502 | 351 | 6.17122 | K -01-06400 | K -01-06382 | 336 | -0.96548 |
| 4078/119 | 4078/100 502 | 343 | 6.17069 | K -01-06382 | K -01-06346 | 298 | 1.12842 |
| 4078/100 502 | 4078/100 501 | 107 | 2.80724 | K -01-06346 | K -01-06335 | 207 | -0.18827 |
| 4078/100 502 | 4078/100 501 | 108 | 2.80674 | K -01-06335 | K -01-09038 | 172 | -0.20341 |
| 4078/300 501 | 4078/1 409 | 274 | -6.50110 | K -01-09038 | K -01-09037 | 254 | -0.22816 |
| 4078/300 501 | 4078/1 409 | 268 | -6.50124 | K -01-09037 | K -01-06272 | 411 | 0.99371 |
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| 4078/1 409 | 4078/1 919 | 359 | -5.05054 | K -01-07657 | K -01-06682 | 277 | 0.34901 |
| 4078/1 919 | 4078/1 719 | 353 | -1.68648 | K -01-06682 | K -01-06179 | 304 | -1.30860 |
| 4078/1 919 | 4078/1 719 | 353 | -1.68687 | K -01-06179 | K -01-08018 | 331 | -1.33861 |
| 4078/1 919 | 4078/1 719 | 352 | -1.68687 | K -01-08018 | K -01-06799 | 445 | -0.08885 |
| 4078/1 719 | 4078/1 519 | 354 | -1.01576 | K -01-06799 | K -01-06109 | 379 | 1.75979 |
| 4078/1 719 | 4078/1 519 | 353 | -1.01575 | K -01-06109 | G.M.1385/1386 | 186 | 1.13816 |
| 4078/1 719 | 4078/1 519 | 354 | -1.01574 | G.M.1385/1386 | K -01-06110 | 255 | 1.52328 |
| 4078/1 519 | 4078/1 319 | 351 | -1.07299 | K -01-06110 | G.M.1384/1385.1 | 150 | 1.19568 |
| 4078/1 519 | 4078/1 319 | 351 | -1.07298 | G.M.1384/1385.1 | K -01-06111 | 28 | 0.58584 |
| 4078/1 519 | 4078/1 319 | 350 | -1.07330 | K -01-06111 | K -01-07444 | 326 | -0.30429 |
| 4078/1 319 | 4078/1 119 | 352 | -1.06147 | K -01-07444 | K -01-07446 | 404 | 2.32751 |
| 4078/1 319 | 4078/1 119 | 352 | -1.06183 | K -01-07446 | K -01-06802 | 427 | 1.08450 |
| 4078/1 319 | 4078/1 119 | 352 | -1.06210 | K -01-06802 | K -01-07593 | 294 | 0.04873 |
| 4078/1 119 | 4078/919 | 353 | 0.50079 | K -01-07593 | K -01-07374 | 119 | -0.44480 |
| 4078/1 119 | 4078/919 | 353 | 0.50024 | K -01-07374 | K -01-07592 | 329 | 0.18962 |
| 4078/1 119 | 4078/919 | 352 | 0.50042 | K -01-07592 | K -01-08007 | 339 | -1.84751 |
| 4078/919 | 4078/719 | 351 | 1.04180 | K -01-08007 | K -01-08070 | 578 | -3.48748 |
| 4078/919 | 4078/719 | 352 | 1.04195 | K -01-08070 | K -01-07536 | 232 | 3.40825 |
| 4078/919 | 4078/719 | 351 | 1.04157 | K -01-07536 | K -01-06024 | 198 | 5.73350 |
| 4078/719 | 4078/519 | 352 | 1.04383 | K -01-06024 | K -01-08191 | 362 | 1.84873 |
| 4078/719 | 4078/519 | 351 | 1.04365 | K -01-08191 | K -01-07535 | 340 | 0.70998 |
| 4078/719 | 4078/519 | 352 | 1.04360 | K -01-07535 | K -01-07103 | 590 | 3.28840 |
| 4078/519 | 4078/319 | 351 | 1.35766 | K -01-07103 | K -01-06876 | 278 | -0.04820 |
| 4078/519 | 4078/319 | 351 | 1.35772 | K -01-06876 | K -01-07522 | 306 | 0.33439 |
| 4078/519 | 4078/319 | 352 | 1.35742 | K -01-07522 | K -01-07106 | 183 | 0.74556 |
| 4078/319 | 4078/119 | 352 | 4.71838 | K -01-07106 | K -01-06981 | 296 | -0.06508 |
| 4078/319 | 4078/119 | 352 | 4.71759 | K -01-06981 | K -01-07594 | 315 | -3.53902 |
| 4078/319 | 4078/119 | 352 | 4.71776 | K -01-07594 | 1-13-09047 | 590 | 3.92598 |
| 4078/119 | 4078/100 502 | 290 | 6.17035 | 1-13-09047 | 1-13-09046 | 180 | 2.83377 |
| 4078/119 | 4078/100 502 | 288 | 6.16971 | 1-13-09046 | 1-13-09045 | 276 | 4.12991 |
| 4078/119 | 4078/100 502 | 289 | 6.17006 | 1-13-09045 | 1-13-09036 | 480 | 10.12574 |
| 4078/100 502 | 4078/100 501 | 107 | 2.80696 | 1-13-09036 | 1-13-09035 | 375 | 4.97433 |
| 4078/100 502 | 4078/100 501 | 106 | 2.80704 | 1-13-09035 | 1-13-09085 | 165 | 4.45871 |
| 4078/100 502 | 4078/100 501 | 107 | 2.80691 | 1-13-09085 | 1-13-09015 | 271 | -0.22734 |
| Copenhagen - Hamlets Grav 1-13-09015 G.I.1806 | | | | | | 42 | -3.35233 |
| 4078/100 501 | 92 164 | 807 | 5.43994 | G.I.1806 | G.I.1805 | 33 | -0.69859 |
| 4078/100 501 | 92 164 | 811 | 5.43855 | G.I.1806 | G.I.1805 | 33 | -0.69862 |
| 92 164 | 1-06-09129 | 608 | 1.25525 | G.I.1805 | 1-02-09016 | 86 | -0.52879 |
| 92 164 | 1-06-09129 | 607 | 1.25497 | 1-02-09016 | 1-02-09154 | 246 | -3.34891 |
| 1-06-09129 | 1-06-09009 | 372 | -2.84618 | 1-02-09154 | 1-02-09235 | 371 | -4.69736 |
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| 1-06-09129 | 1-06-09009 | 345 | -2.84511 | 1-02-09027 | 1-02-09197 | 575 | 0.40066 |
| 1-06-09009 | 1-06-09130 | 322 | 0.29346 | 1-02-09197 | 1-02-09023 | 186 | 1.84284 |
| 1-06-09009 | 1-06-09130 | 329 | 0.29414 | 1-02-09023 | 1-02-09020 | 741 | -3.76828 |
| 1-06-09009 | 1-06-09130 | 313 | 0.29329 | 1-02-09020 | 1-07-09059 | 364 | 0.80726 |
| 1-06-09130 | 1-06-09030 | 458 | -0.42906 | 1-07-09059 | 1-07-09060 | 395 | -1.35958 |
| 1-06-09130 | 1-06-09030 | 437 | -0.42810 | 1-07-09060 | 1-07-09034 | 1271 | -10.35894 |
| 1-06-09130 | 1-06-09030 | 410 | -0.42850 | 1-07-09034 | 1-07-09005 | 278 | 1.13195 |
| 1-06-09030 | 1-06-09029 | 262 | 0.28163 | 1-07-09005 | 1-07-09004 | 956 | 13.25487 |
| 1-06-09030 | 1-06-09029 | 245 | 0.28100 | 1-07-09004 | 1-07-09061 | 199 | -0.12945 |
| 1-06-09029 | K -01-08160 | 939 | -0.40423 | 1-07-09061 | 1-07-09062 | 423 | 2.01512 |
| K -01-08160 | K -01-07231 | 322 | -0.82047 | 1-07-09062 | 1-07-09063 | 608 | -0.32514 |
| K -01-07231 | K -01-07675 | 300 | 1.66577 | 1-07-09063 | 1-07-09066 | 205 | -1.32782 |
| K -01-07675 | K -01-07736 | 431 | -1.27456 | 1-07-09066 | 1-07-09064 | 219 | -2.00371 |
| K -01-07736 | K -01-07800 | 342 | 1.21947 | 1-07-09064 | 1-07-09065 | 463 | -4.81246 |
| K -01-07800 | K -01-07735 | 417 | -0.45409 | 1-07-09065 | 1-14-09047 | 1122 | 21.27404 |
| K -01-07735 | K -01-07805 | 436 | 0.02328 | 1-14-09047 | 1-14-09048 | 640 | -23.19757 |
| K -01-07805 | K -01-07833 | 373 | -0.35008 | 1-14-09048 | 1-14-09003 | 668 | 15.81157 |
| K -01-07833 | K -01-07225 | 680 | -0.86047 | 1-14-09003 | G.I.2097 | 618 | 11.33078 |
| K -01-07225 | K -01-07733 | 262 | 1.89191 | G.I.2097 | 1-14-09012 | 529 | -0.63682 |
| K -01-07733 | K -01-07825 | 384 | -0.60881 | 1-14-09012 | 1-14-09014 | 456 | 4.38710 |
| K -01-07825 | K -01-07559 | 507 | 0.17650 | 1-14-09014 | 13-01-09175 | 979 | -4.89642 |
| K -01-07559 | K -01-08065 | 773 | 0.02748 | 13-01-09175 | 13-01-09176 | 869 | -6.46304 |
| K -01-08065 | K -01-07769 | 612 | 0.12699 | 13-01-09176 | 13-01-09035 | 788 | -0.49027 |
| K -01-07769 | K -01-08163 | 192 | -0.07035 | 13-01-09035 | 13-01-09042 | 320 | -3.92737 |
| K -01-08163 | K -01-06475 | 93 | 0.00546 | 13-01-09042 | 13-01-09055 | 403 | 0.40165 |
| K -01-06475 | K -01-07438 | 205 | 0.44600 | 13-01-09055 | 13-01-09155 | 1170 | 2.10255 |
| K -01-07438 | K -01-06817 | 612 | 0.78750 | 13-01-09155 | 13-01-09079 | 507 | 6.73383 |
| K -01-06817 | K -01-06429 | 193 | -0.54556 | 13-01-09079 | 13-01-09157 | 764 | -9.16765 |

|  |  |  |  |
| --- | --- | --- | --- |
| 13-01-09157 | 13-01-09178 | 722 | 9.13745 |
| 13-01-09178 | 13-01-09152 | 1055 | -21.76584 |
| 13-01-09152 | 13-01-09068 | 895 | 7.78135 |
| 13-01-09068 | 13-03-09002 | 896 | -4.22455 |
| 13-03-09002 | 13-03-09001 | 464 | -2.71519 |
| 13-03-09001 | 13-05-09079 | 572 | -3.37719 |
| 13-05-09079 | 13-05-09070 | 776 | -1.59310 |
| 13-05-09070 | 13-05-00802 | 812 | -0.27505 |
| 13-05-00802 | 13-05-09001 | 1226 | -7.19419 |
| 13-05-09001 | 13-04-09010 | 1069 | 6.07794 |
| 13-04-09010 | G.M.1330 | 483 | 0.18952 |
| G.M.1330 | 13-04-09083 | 146 | -0.64267 |
| 13-04-09083 | 13-04-09026 | 836 | -2.65811 |
| 13-04-09026 | 13-04-09006 | 893 | -16.91665 |
| 13-04-09006 | 13-04-09004 | 737 | 20.48722 |
| 13-04-09004 | G.M.1332 | 938 | -8.08294 |
| G.M.1332 | 12-01-09154 | 1203 | 1.05930 |
| 12-01-09154 | 12-01-09155 | 1279 | 14.69375 |
| 12-01-09155 | 12-01-09156 | 919 | 11.36368 |
| 12-01-09156 | G.M.1334 | 822 | 7.37570 |
| G.M.1334 | 12-02-09010 | 722 | 1.49622 |
| 12-02-09010 | 12-02-09019 | 1139 | -9.99446 |
| 12-02-09019 | 12-06-09058 | 641 | -3.24903 |
| 12-06-09058 | 12-06-09113 | 116 | -0.46502 |
| 12-06-09058 | 12-06-09113 | 99 | -0.46534 |
| 12-06-09113 | 12-02-09016 | 602 | -9.48240 |
| 12-02-09016 | 12-02-09008 | 873 | 12.68619 |
| 12-02-09008 | 12-02-09006 | 943 | 1.08087 |
| 12-02-09006 | 12-02-09033 | 822 | 3.40791 |
| 12-02-09033 | 12-02-09066 | 917 | -4.44607 |
| 12-02-09066 | K -06-09202 | 867 | 13.90090 |
| K -06-09202 | K -06-09166 | 1024 | -20.86354 |
| K -06-09166 | K -06-09062 | 204 | 4.93669 |
| K -06-09062 | K -06-09138 | 983 | -10.55822 |
| K -06-09138 | K -06-09064 | 442 | -1.46610 |
| K -06-09064 | K -06-09072 | 733 | 2.22171 |
| K -06-09072 | G.I.1607 | 238 | -5.87435 |
| Kärnan: foundation wall - tower chamber | | | |
| 032\*1\*3124 | 032\*2\*3109 | 40 | 6.98720 |



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