Influence of horizontal Refraction on the traverse Measurements in Tunnels with Small Diameters

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Abstract

The Institute for Deposits and Surveying of the Deutsche Montan Technologie (DMT), Bochum, delivered 3 high precision gyrotheodolites GYROMAT to the English-French-syndicate for the construction of the tunnel under the English Channel. The GYROMATS are in use for direction-finding during the construction of the EUROTUNNEL from both sides.

Furthermore, DMT surveying teams are carrying out verification surveys both on the French and on the British side to guarantee a successful breakthrough under the English Channel in autumn of 1990.

The GYROMAT and the EUROTUNNEL-project will be outlined in this paper.

Finally the influence of horizontal refraction on traverse measurements in tunnels is discussed.

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1. The GYROMAT Gyrotheodolite

For north finding by means of gyrotheodolites, normally methods for observation of discrete oscillation points (reversing point methods) and transit methods (time difference methods) are used. In case of gyroscopic systems which automatically orient themselves northwards, generally the whole unit is pivoted until the gyroscope's and the whole theodolite's orientation are coincident.

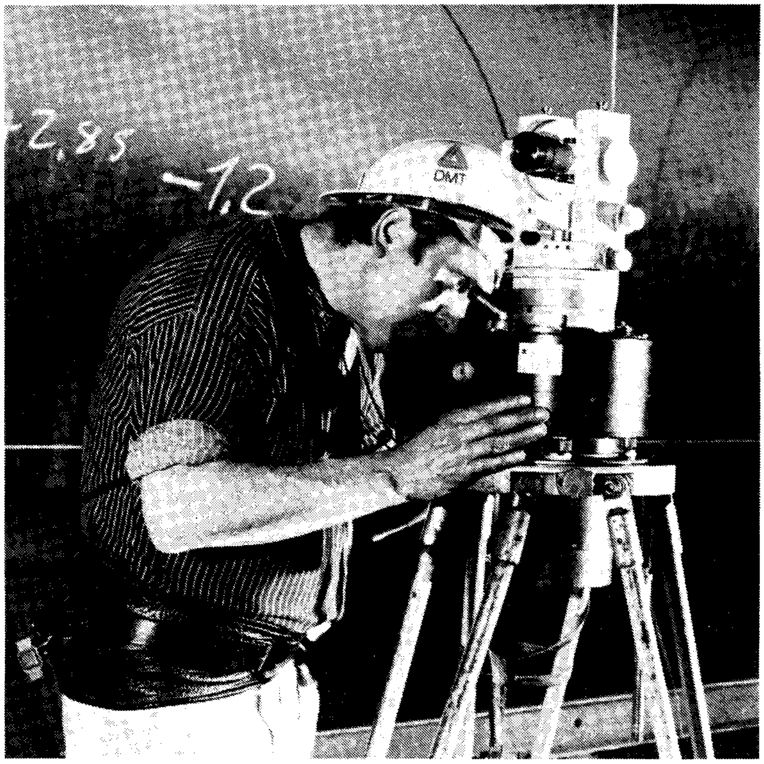

Fig. 1: Cyromat gyrotheodolite in use below ground

With GYROMAT, the most recent gyrotheodolite design resulting from 35 years of research and development work of DMT, north finding is run continuously by automatic measurements of only one gyroscope oscillation at small amplitude. For this purpose, the free gyroscope oscillation is measured by an opto-electronic pick-up over a period T, and integrated as shown on Fig. 2.

The zero mark of the pick-up, after iterative preliminary orientation, still shows a deviation α_K relative to the resulting oscillation center R (= the resultant of tape-induced and gyroscope-induced torque) and an orientation deviation α_N relative to the geographical north. α_N results from the equilibrium condition of torques, i.e. between the gyroscope-induced directional torque and the tape-induced torque. The amount of the integral yields α_K. The orientation deviation α_N to be arrived at is calculated by simple multiplication of α_K by (1 + X) (KORITTKE, 1988).

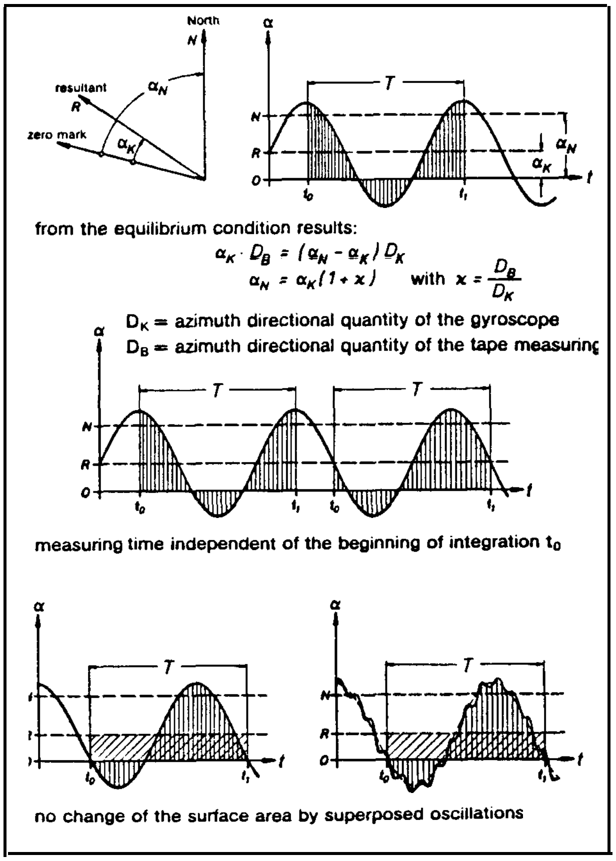

Fig. 2: Integration method for GYROMAT

The advantages of this integration method are obvious:

> The amount of the integral is independent on the time of beginning of integration, i.e. there is no need for a preferred point of the curves constituted by oscillations. The measuring time therefore is of one oscillation period T independently on the momentary oscillation figure, and thus constitutes the *shortest-possible* measuring time for an automatic gyrotheodolite.

The measuring time T is only dependent on the geographical latitude B, e.g.:

B = 0° , T = 150 sec.

B = 55° , T = 170 sec.

B = 75° , T = 210 sec.

- The amount of the integral of the oscillation and thus of the values α_K and α_N is not changed by superposed natural oscillations (Fig.2), and this means that the result of measurement is less affected e.g. by soil vibrations as occurring on building sites.

- If disturbing influences, such as rectifier moments result in oscillation drift which inevitably results in affecting orientation deviation, this is identified when integrating the oscillation, and displayed on the electronics unit.

A GYROMAT measuring procedure is run as follows:

- tape zero position measurement	approx. 1 minute
- iterative preliminary orientation	approx. 3-4 minutes
- gyroscopic measurement (B = 45° to 60°)	approx. 3 minutes

The deviation from North of the graduation ring is thus shown on the electronics unit after a total measuring time of approx. 7 to a minutes.

Comprehensive investigations carried out by KORITTKE and SCHMIDT (1986) show an exactitude of the azimuth determination by GYROMAT corresponding to a standard deviation of < ± 0.9 mgon.

Short measuring times, reliability, and high exactitude were reasons enough to the builders of the EUROTUNNEL to use on each heading GYROMAT for direction finding.

2. The EUROTUNNEL project

2.1. Design and Construction

The long history of the land connection between England and France started in 1753 when the French engineer Nicolas Desmaret designed the first tunnel project. The second bold project of a tunnel with petroleum lamp lighting for the horse-drawn carriages was submitted to Napoleon Bonaparte in 1803. Things started to become serious not before 1866 when a new design was highly appreciated by Napoleon III and commented quite enthusiastically by Queen Victoria who easily became seasick. Work started in 1878. Suddenly, however, fear of invasion haunted the British, more exactly the military authorities, even though plans had been made for flooding the tunnel in case of military emergency. Drilling work was stopped in 1883 after 2 km of advance on both sides (BONAVIA 1987).

Shortly before the First World War the matter was discussed again, however, serious negotiations did not restart before the mid-fifties. In the seventies, substantial action was taken with the second start of tunneling. Again the drilling machines were on the job. However, in 1975 work was stopped again, this time after 0.8 km of advance on the British side and 1.2 km of advance on the French side. The Labour government under Prime Minister Harold Wilson argued in terms of costs.

This arguing is nowadays out of question for the governments. The EUROTUNNEL consortium is a merely private company which finances the calculated costs for the construction, an amount of 7.6 billion **£,** by credits (8O%) and shares (20%).

The line of the twin railway tunnel is shown on Fig. 3

The tunnel is the connection of two terminals for loading and unloading of trucks and passenger cars on the trains and from the trains respectively. The journey from terminal to terminal will take only 33 minutes at speeds of up to 160 km per hour.

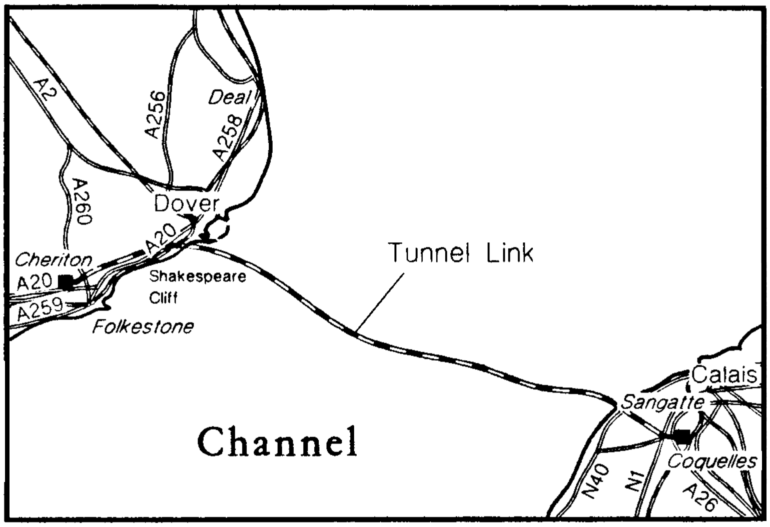

Fig. 3: Course of the EUROTUNNEL

37 km of the EUROTUNNEL are headed directly underneath the English Channel in a depth of 25 to 40 m below the sea bottom. On the French side further 3.5 km are to be headed underneath the coast while on the English side 10 km are headed before the tunnel portals are reached (Fig. 4). The total length of a tunnel will be approx. 50.5 km. From the French side 19.1 km need to be headed to the point of cut-through while 31.4 km are to be headed from the British side.

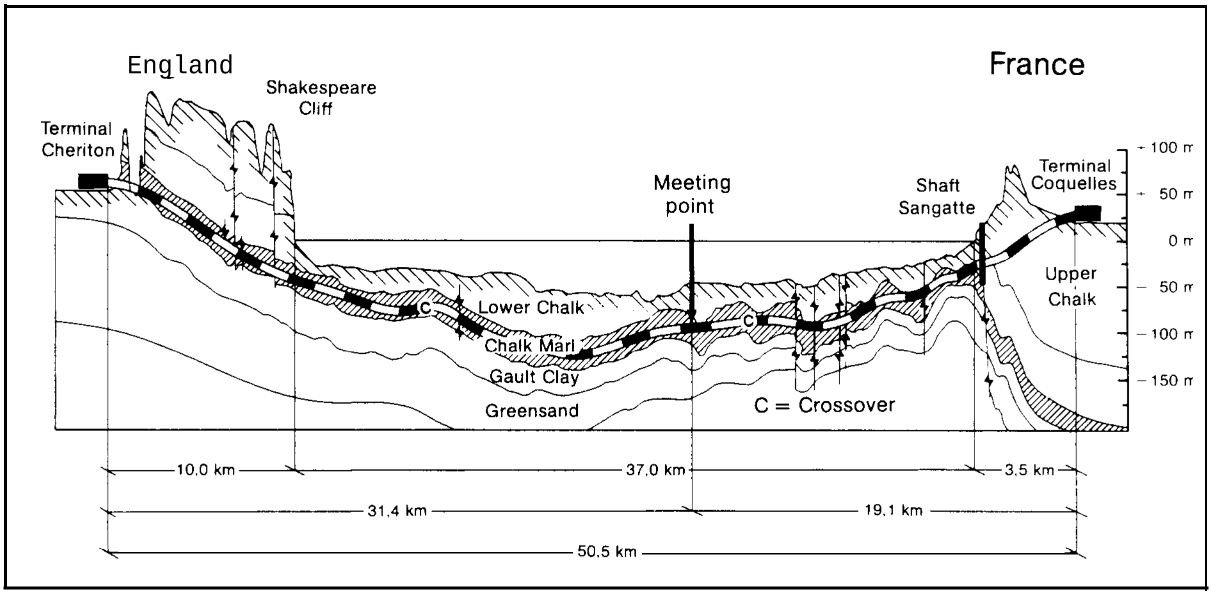

Fig. 4: EUROTUNNEL - geological features, vertical profile

The tunnel will pass along a massive 20 m to 35 m thick layer of watertight Chalk Marl. This Chalk Marl lies under a layer of Upper and Lower Chalk and assures good conditions for heading the tunnels by fullface tunneling machines. The layer of Chalk Marl is not level, and its thickness from one side of the Channel to the other is not constant. Therefore, the 200 m long tunneling machines have to build a number of curves; horizontal and vertical curves as shown in Fig. 3 and Fig. 4.

A total of 11 machines is used for heading, 6 on the British side and 5 on the French side. Both railway tunnels in a distance of 15 m each from a central service tunnel of 4.8 m diameter are headed with a diameter of 7.6 m. Pre-cast concrete or cast-iron segmental linings are installed immediately behind the excavation.

In 375 m intervals, cross-passages are provided between all 3 tunnels. They serve as emergency exits, for maintenance, and for compensating the pressure waves ahead of the trains in motion (Fig. 5). For the same reasons, a 2 m diameter pressure-relief duct every 250 m will link the two running tunnnels.

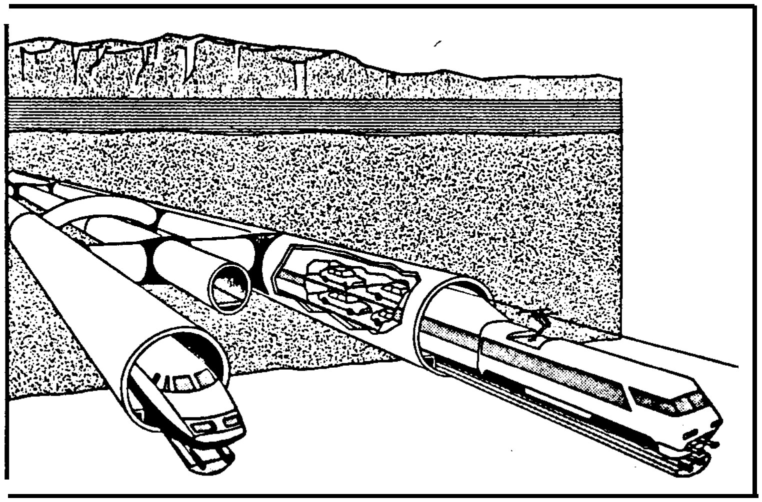

Fig. 5: EUROTUNNEL - general scheme

The central service tunnel serves during heading work as pilot tunnel which is headed approximately 2 to 7 km ahead of the railway tunnels. For prospection of the geological conditions, additional horizontal drillings through the cutting head of the tunnel boring machines for the service tunnel are envisaged in order to allow in time appropriate special measures possibly to be taken in case of geological anomalies.

2.2. Heading work from the French side

On the French side, not far from the Channel coast, a 63 m deep shaft with 55 m of diameter was sunk near the township of Sangatte.

From the shaft bottom plate in 48 m depth the 6 assembly chambers for the tunnel boring machines - for the landwards heading of approx. 3.3 km to the surface and the 15.8 km heading seawards to the cut-through point underneath the Channel - may be recognized.

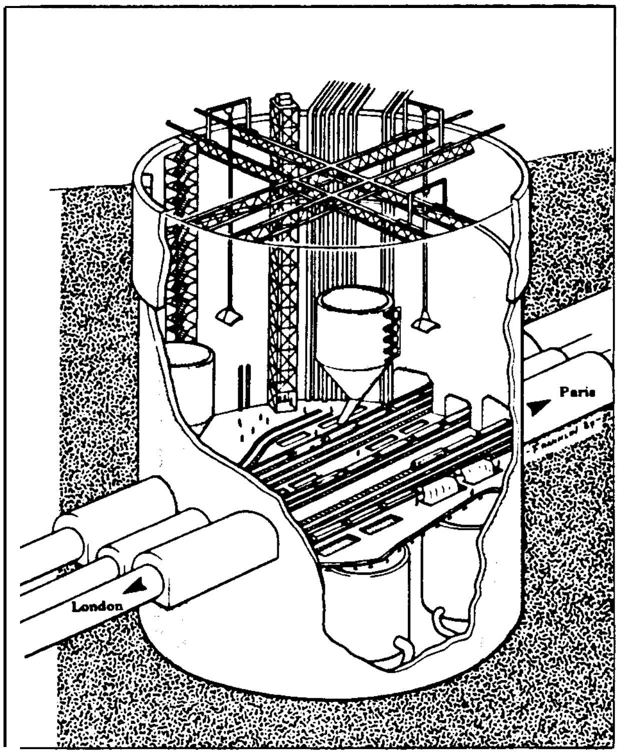

Fig. 6: Sangatte shaft - project and construction drawing

2.3. Heading work from the British Side

UK tunnels are constructed from a work area at Shakespeare Cliff, three parallel headings being driven about 10.0 km landward and three about 22.1 km seaward to the meeting point with the French drives.

The main work area at Shakespeare Cliff - the Lower Site - is a terrace below the chalk cliffs just west of the tunnel line and about 16 metres above sea level, reached by a road tunnel from the Upper Site at the top of the cliffs.

From the Lower Site two inclined adits descend north-easterly to intersect the main Tunnel line landward of the coast, and in this intersection area enlargements of the three tunnels are constructed to form an underground operations area known as the Marshalling Tunnels. A vertical Access and Ventilation Shaft at the NE side of the Marshalling Tunnels provides a direct connection to the Upper Site.

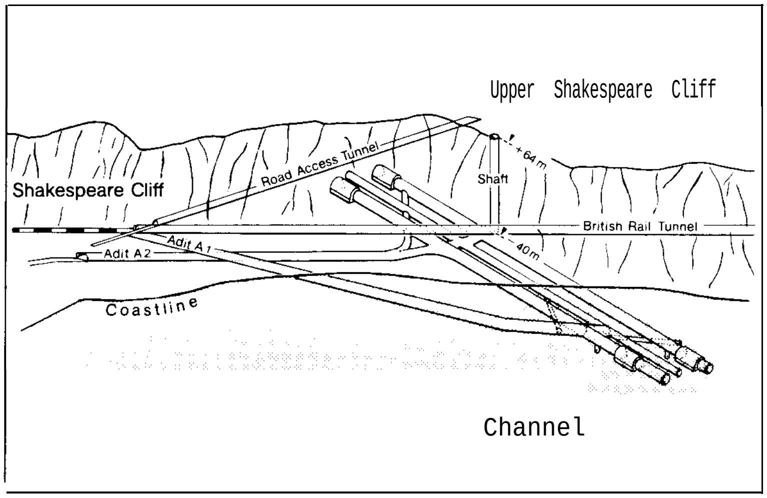

Fig. 7: Shakespeare Cliff - Marshalling Area

3. DMT - Verification Surveys in the EUROTUNNEL

Influence of horizontal refraction on traverse measurements in the Service Tunnel is shown with the results of two survey campaigns on the British side. The first survey campaign was carried out in March 1989. 6 kilometres tunnel drive of the Marine Service Tunnel were checked within this campaign. Fig. 8 shows the traverse configuration which was observed. The points C1, C2 and F are concrete pillars on the Upper Shakespeare Cliff. These three points belong to the EUROTUNNEL-network between France and Great Britain. The points A2/1 and A2/2 are concrete pillars situated in the Adit A2; all other points are special brackets fixed to the permanent linings.

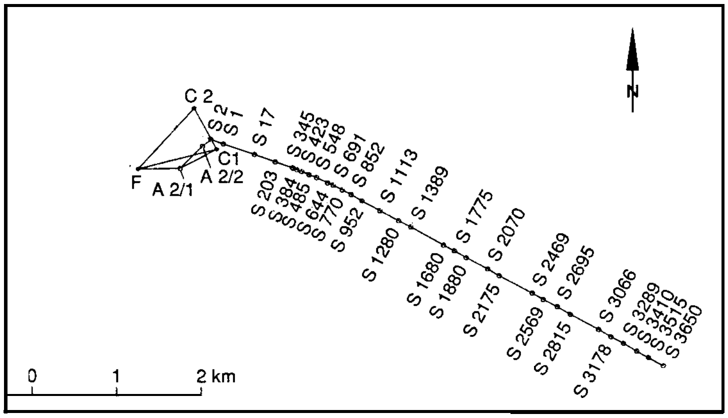

Fig. 8: Verification Survey (GB) 3/89
Traverse configuration

The Service Tunnel, during the construction period, is densely fitted out with the various services required for the driving process, including water and drainage pipes, power supplies, ventilation ducts, signaling and communication cables, and twin rail tracks, as indicated in Fig. 9.

The limitations on usable space for surveying led to the design of brackets which are situated very close to the wall of the tunnel. A set of three V-grooves at 120 degree spacing are incorporated into the brackets to provide forced centring for all normal instruments using a standard WILD pillar plate. To accommodate the lower portion of the GYROMAT a large circular hole is provided in the brackets.

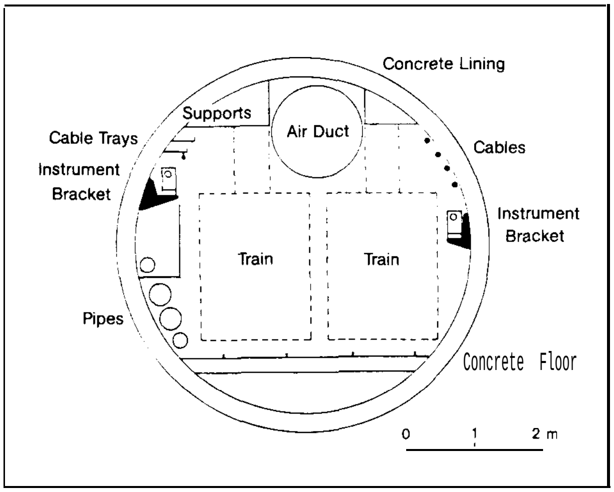

Fig. 9: Service Tunnel - Cross Section

The alternate position of the brackets at the right-hand and left-hand side of the tunnel allowed a strong zig-zag route for traversing and it was expected that horizontal refraction could be avoided.

Angle and distance measurements were done using WILD T2002 in combination with WILD DI2000 and WILD GRE4 data loggers. Azimuth determination with GYROMAT was carried out as shown in Fig.10.

Reciprocal observations with the GYROMAT on same traverse lines were done measuring azimuths twice at each point. The size of the refraction angle Δ was in the range of up to 2.0 mgon.

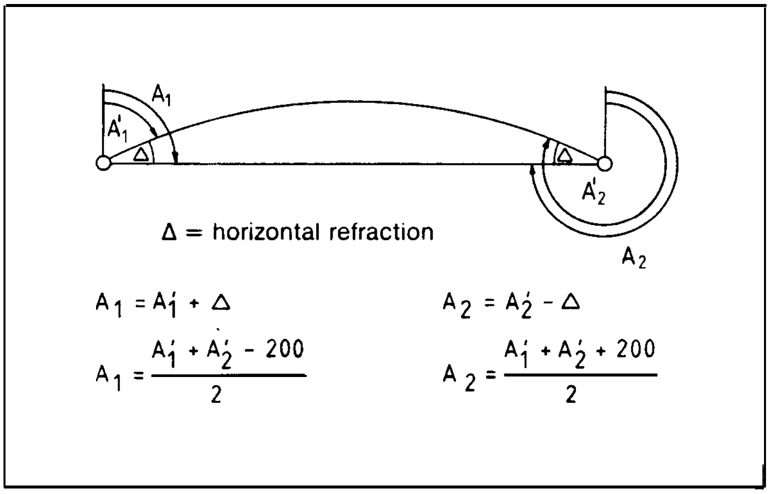

Fig.10: Measuring array for eliminating and detecting horizontal refraction with gyroscopic measurements

Table 1 shows the bearings of each traverse line after an adjustment of the traverse with and without gyro observations. The differences of the bearings between the optical and gyro-supported traverse is shown in column (3). The last column shows the swing between the two different traverse calculations.

Mainly at the beginning of the tunnel, between km 1.0 and km 3.5, where a strong curve to the right-hand side can be recognized, the differences between the bearings are more increasing than in the straight part of the tunnel.

The second survey campaign was carried out in December 1989/January 1990 during the New Years shutdown, when no working activities in the tunnels took place. This time it was possible to measure a centre-line traverse. Some weeks before the campaign, special plates out of steel with V-grooves for forced centring were installed in the concrete floor of the tunnel between the two rail tracks. Using special stools, which were made out of aluminum with a foot similar to that of a standard WILD pillar-plate, a traverse in the middle of the tunnel was observed.

Table 1: EUROTUNNEL - Verification Survey

Great Britain 3/89
Zig-Zag-Traverse

From	To	Bearing after adjustment		Diff. (1)-(2) [mgon] (3)	Length of Traverse [km] (4)	Swing [mm] (5)
		with GYROMAT (1)	without GYROMAT (2)			
A2/1	A2/2 *	49.4450	49.4457	-0.7	0.372	3
A2/2	MTS2 *	56.5071	56.5080	-0.9	0.499	4
MTS2	MTS1 *	122.8067	122.8074	-0.7	0.655	6
MTS1	17	119.8158	119.8155	+0.3	1.042	4
17	203	121.4786	121.4774	+1.2	1.302	3
203	345	120.8653	120.8631	+2.2	1.516	10
345	384 *	128.1011	128.0979	+3.2	1.575	12
384	423	119.5116	119.5079	+3.7	1.634	16
423	485	127.8503	127.8461	+4.2	1.728	22
485	548	123.1891	123.1844	+4.7	1.822	29
548	644	128.8531	128.8478	+5.3	1.967	41
644	691	124.4496	124.4437	+5.9	2.038	48
691	770 *	131.4425	131.4360	+6.5	2.158	60
770	852	128.4224	128.4145	+7.9	2.280	75
852	952	133.2877	133.2783	+9.4	2.431	97
952	1113	130.6273	130.6165	+10.8	2.673	138
1113	1280 *	132.7052	132.6930	+12.2	2.924	187
1280	1389 *	130.0523	130.0395	+12.8	3.088	220
1389	1680 *	132.2658	132.2527	+13.1	3.526	310
1680	1775 *	129.8136	129.8003	+13.3	3.669	340
1775	1880 *	133.3176	133.3037	+13.9	3.827	374
1880	2070 *	130.7208	130.7062	+14.6	4.113	440
2070	2175 *	133.3090	133.2939	+15.1	4.271	477
2175	2469 *	131.0435	131.0287	+14.8	4.713	580
2469	2569 *	133.3729	133.3580	+14.9	4.863	615
2569	2695 *	130.2317	130.2162	+15.5	5.052	661
2695	2815 *	133.0986	133.0822	+16.4	5.232	708
2815	3066 *	130.9558	130.9387	+17.1	5.609	809
3066	3178 *	133.2237	133.2060	+17.7	5.777	856
3178	3289 *	130.1029	130.0851	+17.8	5.944	903
3289	3410 *	131.6857	131.6682	+17.5	6.126	953
3410	3515	131.6927	131.6749	+17.8	6.284	988
3515	3650 *	131.6781	131.6605	+17.6	6.487	1052

* traverse line with gyro-measurements

Table 2: EUROTUNNEL - Verification Survey

Great Britain 12/89

Centre-Line-Traverse

From	To	Bearing after adjustment with GYROMAT (1)	Bearing after adjustment without GYROMAT (2)	Diff. (1)-(2) [mgon] (3)	Length of Traverse [km] (4)	Swing [mm] (5)
A2T	A2M	50.9911	50.9911	0	0.496	0.2
A2M	ENT *	120.4663	120.4664	-0.1	0.762	0.3
ENT	T5 *	120.7411	120.7411	0	1.031	0.3
T5	171	120.4814	120.4812	0.2	1.255	0.5
171	296	121.4060	121.4056	0.4	1.443	1.7
296	436	123.5396	123.5390	0.6	1.654	3.8
436	568 *	125.7719	125.7711	0.8	1.855	6.5
568	709	127.6997	127.6987	1.0	2.066	9.8
709	859	130.1423	130.1411	1.2	2.292	14.1
859	1018	131.6562	131.6548	1.4	2.531	19.2
1018	1294 *	131.6672	131.6657	1.6	2.946	29.3
1294	1548	131.6636	131.6618	1.8	3.328	39.9
1548	1827	131.6631	131.6605	2.6	3.748	52.8
1827	1982	131.6358	131.6336	2.3	3.981	61.1
1982	2095 *	131.6327	131.6302	2.5	4.151	67.7
2095	2234	131.6988	131.6963	2.5	4.360	75.8
2234	2369	131.5948	131.5923	2.5	4.563	83.8
2369	2498	131.6456	131.6432	2.4	4.756	91.2
2498	2622 *	131.6204	131.6179	2.5	4.943	98.5
2622	2868	131.6293	131.6268	2.5	5.312	113.0
2868	3121	131.6624	131.6599	2.5	5.693	128.2
3121	3270 *	131.6767	131.6741	2.6	5.916	137.2
3270	3410	131.6813	131.6788	2.5	6.127	145.4
3410	3682	131.6758	131.6734	2.4	6.536	160.8
3682	3850	131.6875	131.6852	2.3	6.787	169.9
3850	4036 *	131.6758	131.6737	2.1	7.068	179.0
4036	4297	131.6532	131.6514	1.8	7.461	189.9
4297	4441 *	129.5053	129.5038	1.5	7.677	195.0
4441	4584	126.1020	126.1006	1.4	7.893	199.7
4584	4728	127.2179	127.2165	1.4	8.109	204.4
4728	4868 *	130.6272	130.6259	1.3	8.319	208.6
4868	5008	133.9648	133.9635	1.3	8.530	212.9
5008	5139	137.1472	137.1458	1.4	8.727	217.1
5139	5279	136.4768	136.4754	1.4	8.938	221.7
5279	5419 *	133.1197	133.1182	1.5	9.148	226.6
5419	5546	131.6845	131.6829	1.6	9.339	231.1
5546	5722	131.6909	131.6894	1.5	9.412	237.6
5722	5857	131.6809	131.6793	1.6	9.615	242.9
5857	5994 *	132.5372	132.5355	1.7	9.821	248.4
5994	6136	134.6789	134.6769	2.0	10.035	254.9
6136	6268 *	136.8510	136.8488	2.2	10.234	261.7
6268	6412	139.0447	139.0422	2.5	10.447	270.0
6412	6558 *	141.3381	141.3354	2.7	10.670	279.4
6558	6705	143.7011	143.6979	3.2	10.890	290.3
6705	6846 *	145.9892	145.9856	3.6	11.103	302.0
6846	6985	147.6905	147.6865	4.0	11.312	314.8
6985	7187 *	147.8379	147.8336	4.3	11.615	334.9
7187	7392	147.8528	147.8482	4.6	11.924	356.5
7392	7574 *	147.8278	147.8230	4.8	12.198	376.6
7574	7725	147.8456	147.8406	5.0	12.425	393.9
7725	7903 *	147.8596	147.8542	5.4	12.692	416.6
7903	8050	147.8313	147.8250	6.3	12.913	437.9
8050	8222 *	147.8339	147.8270	6.9	13.172	465.9
8222	8396	147.8538	147.8466	7.2	13.433	495.0
8396	8544 *	147.8352	147.8278	7.4	13.656	520.7

* traverse line with gyro-measurements

Table 2 shows the results of the centre-line traverse. The differences of the bearings between the optical and gyro-supported traverse are eight times smaller compared with those values obtained from the zig-zag traverse; the influence of horizontal refraction is extremely less than on the brackets near the wall of the tunnel. Nevertheless the swing of the optical traverse turns to the same direction compared with the experiences out of the zig-zag traverse. This is again referable to the curves of the tunnel to the right-hand side at the beginning as mentioned and those between km 9.6 and km 11.6 where the values of the differences are increasing.

It must be mentioned, that on the French side of the tunnel course under the Channel begins with a strong curve to the left-hand side and the swing of the optical traverse shows to the opposite direction.

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