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## **THE THIRD HIGH PRECISION LEVELLING OF SWEDEN**

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The first high precision levelling of Sweden was carried out between 1886 and 1905. The network comprised twelve closed loops and sixteen spur lines connecting the network to mareographs and to bench marks in Norway and Finland, see fig. 1. A total of 4857 km were levelled with 75% of the lines along railways and the remaining 25% along roads. The final adjustment gave a standard error per km of  $\pm 4,4$  mm. Of the 2500 bench marks that were established, 800 were marked in bed-rock and the remainder in large rock outcrops, stones, house foundations etc.

The second high precision levelling was begun forty-six years later and took sixteen years to complete. Fig. 1 indicates the extent of this second levelling which covered a much larger area of the country than the earlier levelling. A total of 10 389 km were levelled in 27 closed loops. Three other loops which incorporate Norwegian and Finnish lines were also observed. Connections were also made to mareographs. With few exceptions, all the lines in the first precision levelling were relevelled and included in the new net. Network configuration was considerably improved as was area coverage as a result of the newly measured loops. As was the case with the first levelling, the greater number of lines - 75% - were located along railway lines.

The quality of the second levelling, although not of the highest international standard, was superior to the first, see table 1. The permitted difference between forward and reverse levelling of a line between two adjacent bench marks was  $2\sqrt{L}$  mm (L in km), and the adjustment of the network gave a standard error of  $\pm 1.63$  mm/km. A total of 7420 new bench marks were levelled between 1951 - 1967 and, in addition, approximately 900 bench marks from the first levelling and a further 600 in local level networks were relevelled and incorporated. Stainless steel pins let into rock is the most common type of marker, and of these, 3670 are in bed rock and 3120 in rock outcrops of varying sizes, house and bridge foundations. A new type of marker for use in areas without rock or rock outcrops was developed. A total of 650 markers of this type were used.

The datum point for the 1886 - 1905 levelling was located in the old city of Stockholm and its height was determined from mareograph observations from a number of stations distributed along the coast. The Epoch 1900 height system is based on this bench mark which was given a height of 11.800 m above m.s.l. 1900. This height system is still in use in many parts of the country. Following the completion of the second levelling a recomputation of all data including those second and third order which had been observed principally for mapping purposes was begun. Height system Epoch 1970, as this system is called is, in principle, based on the Amsterdam datum value which was used for the 1960 European Levelling Adjustment. A new datum point was established in Varberg in south-west Sweden to replace the Stockholm datum point.

A comparison between high precision levelling networks in four Nordic countries is given in table 1.

During the past 70 years the high precision networks have been successively densified by measuring second and third order loops of levelling. A typical second order loop has a perimeter length which varies from 100 km to approximately 220 km. A total length of approximately 26 000 km of second order levelling has been measured during this period. Fifteen thousand second order bench marks have been established, with an average distance between them of 2 km. The quality of the second order networks is extremely uneven. Although all lines were observed in forward and reverse directions, the permitted difference between the forward and reverse levelling of two adjacent bench marks has varied from  $20\sqrt{L}$  mm to  $4\sqrt{L}$  mm. The quality of the station marks is also very uneven.

The third order networks are generally of low quality and were measured mainly for topographic mapping purposes. The lines were measured in only one direction and very long lines of sight were permitted. Approximately 40 000 third order bench marks have been established. A total of 100 000 bench marks of first, second and third order have been demarcated and measured since the turn of the century.

The present situation is such that approximately 30% of these bench marks have been destroyed, approximately 30% of the remaining bench marks are considered to be unstable - in loose rock or large stones which can be disturbed by frost mechanics - and, of the remainder, a large proportion are located on railways with difficult access.

The present situation is very difficult and will very soon become intolerable. For this reason a Working Group was appointed with instructions to carry out a detailed study of the present state of the network and thereafter, where necessary, suggest measures which should be taken to establish a network of acceptable international standard.

In its final report (1) the Group stated that:

1. the study of the network had revealed serious weaknesses and deficiencies.
2. these deficiencies could only be remedied by carrying out a complete remeasurement programme.
3. a notable weakness in the older networks was the poor stability of many of the bench marks, and that the question of how and where bench mark should be established must be paid greater attention than previously.
4. the motorized levelling techniques which had been developed, tested and very successfully applied in second order networks since 1974 should be used in the new programme.

The Working Group also recommended that:

1. the new lines of high precision levels should be located along roads instead of, as previously, along railway lines.
2. that the existing second order network should where

necessary be redemarcated, densified and relevelled

3. all lines should be relevelled with the same accuracy, with a maximum difference between forward and reverse levelling of  $\Delta h$  between two adjacent bench marks of  $2\sqrt{L}$  mm.
4. the releveling should begin on a limited scale in 1979 and that the number of field parties should be increased as the retriangulation programme approaches completion
5. the remeasurement programme should be completed within 10 - 15 years.
6. the remeasurement programme should be co-ordinated with similar remeasurement programmes which are planned in Norway, Denmark and Finland.

This third high precision levelling will serve two main purposes: it will provide high quality height information for scientific purposes such as land uplift studies, and it will provide a reasonably dense network of good and homogeneous quality for land survey purposes. All levelling networks must, according to Swedish Survey Regulations, be connected to the national network. These regulations cannot and should not be enforced unless accuracy in the higher order bench marks can be guaranteed and the density of the net is sufficient to ensure easy connections. These latter requirements will be met by the new network which will be further densified in the vicinity of towns and cities. The average distance between bench marks will be approximately 1200 metres and a typical loop perimeter length will be not greater than 100 km.

Demarcation problems have been paid a great deal of attention in accordance with the Working Group's recommendations. Geological conditions vary considerably from area to area in Sweden despite an abundance of surface rock. To improve the quality of the bench marks the Swedish Geotechnical Institute has been engaged in the training of reconnaissance parties. Attention has been paid to local plate tectonics both in connection with location of bench marks and observing programmes.

As was the case with the retriangulation of Sweden, and for similar reasons, the country will be divided into fourteen regions, see fig 2. Heights will be computed and made available as soon as possible after completion of the field work. Computation of the fourteen regions will be based on Epoch 1970 heights and the new network will be given the best possible fit to the existing precision levelling net. This will be done for purely practical purposes. Acceptance of Epoch 70 system took considerable time and to introduce a third system would meet with considerable opposition from land surveyors. Therefore, the best way to take full advantage of the improved accuracy of the new measurements and to put them into use as soon as possible is to base the new heights on the existing system.

When the whole network has been levelled a scientific adjustment will be carried out.

A total of more than 40 000 km of double levelling will be carried out using motorized levelling techniques. A limited amount of levelling using classical methods will be necessary to connect bench marks along railway lines to the new lines along the roads. The programme will cost between 40 000 000 and 50 000 000 Swedish kronor.

Motorized levelling techniques have been described in detail in (2) and (3). Although the technique was developed in East Germany, significant improvements both in field techniques and instrumentation have been made at the NLS. The effectivity of motorized techniques as compared with classical techniques is shown in fig 3. Motorized levelling is also approximately 20 % cheaper per km than classical levelling.

An integrated system is being developed for field booking, computing and archive storage. Data stacks are planned to be used for "booking" field observations with facilities for obtaining a check print-out in the field.

Finally computed heights together with intermediate data will be stored in data bases with rapid retrieval possibilities. The question of how to store station descriptions is still under discussion. Microfilming is one suggested solution.

When the levelling programme is completed Sweden will have both fundamental triangulation and levelling networks of high international class.

#### References

- 1) The second high precision levelling of Sweden 1951-1967.  
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- 2) Becker, JM: Experiences using Motorized Levelling Techniques in Sweden.  
FIG - STOCKHOLM 1977.
- 3) Becker, JM: Heutige Messverfahren beim Nivellement.  
Erfahrungen mit dem Motorisierten Niv. in Schweden.  
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- 4) Renewal of the National High Precision Levelling Network.  
Report from the Working Group.

Table 1. Comparison of high precision levelling in Nordic Countries

	DENMARK		NORWAY	FINLAND		SWEDEN	
	1:a	2:a		1:a	2:a	1:a	2:a
Year	1885-94	1943-53	1916-53	1892-1910	1935-55	1886-05	1951-67
Number of loops	17	23				12+16	27+27
Length km			8468	3955+1216	5936	4857	10389
along railways (%)			25	68	70	75	75
along roads (%)			75	32	30	25	25
Number of bench marks			3822		3400	2500	9 000
Distance between bench marks (km)	1,8		2-3	1,9	1,8	2	1,4
Standard error mm/km	-	0,84	1,38	1,47	0,64	4,4	1,63

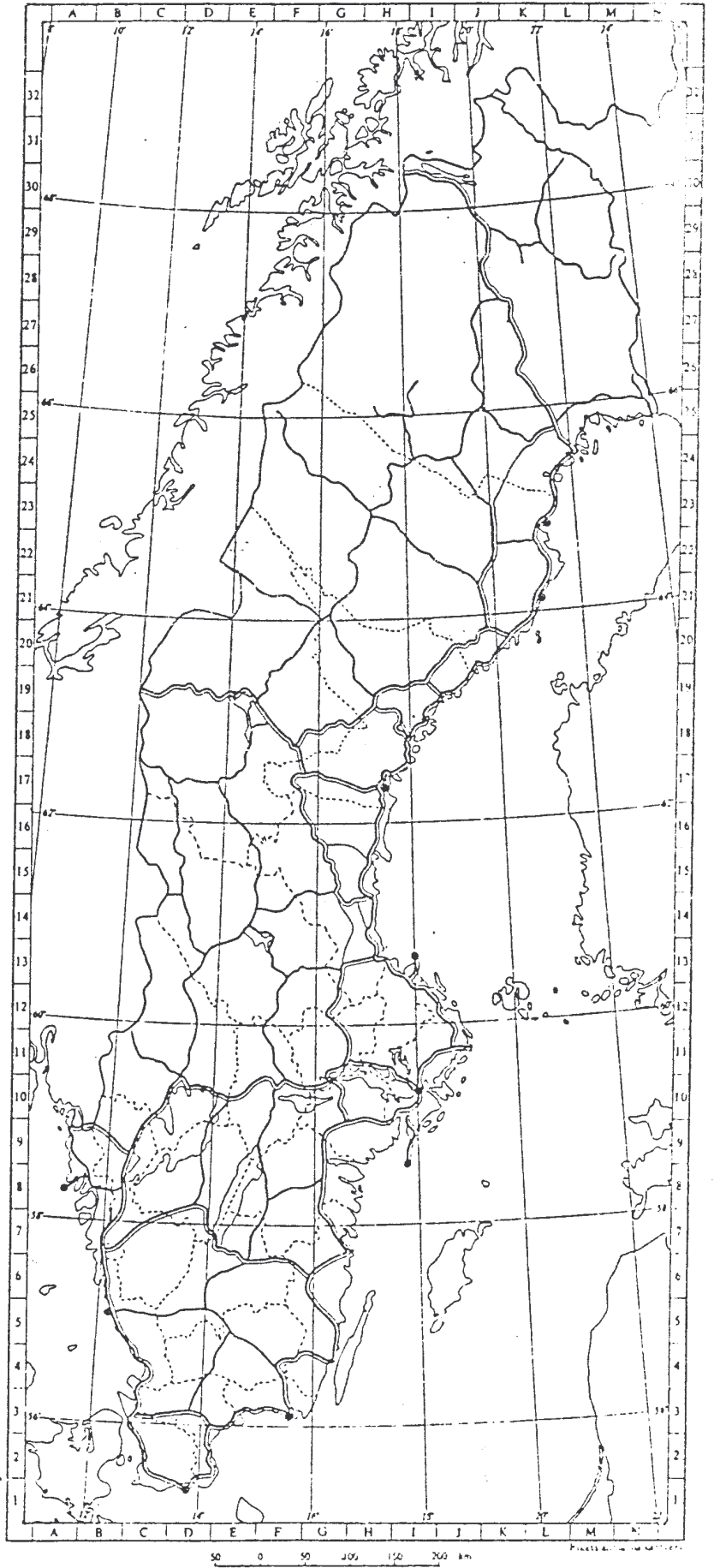


Fig 1. High precision levelling

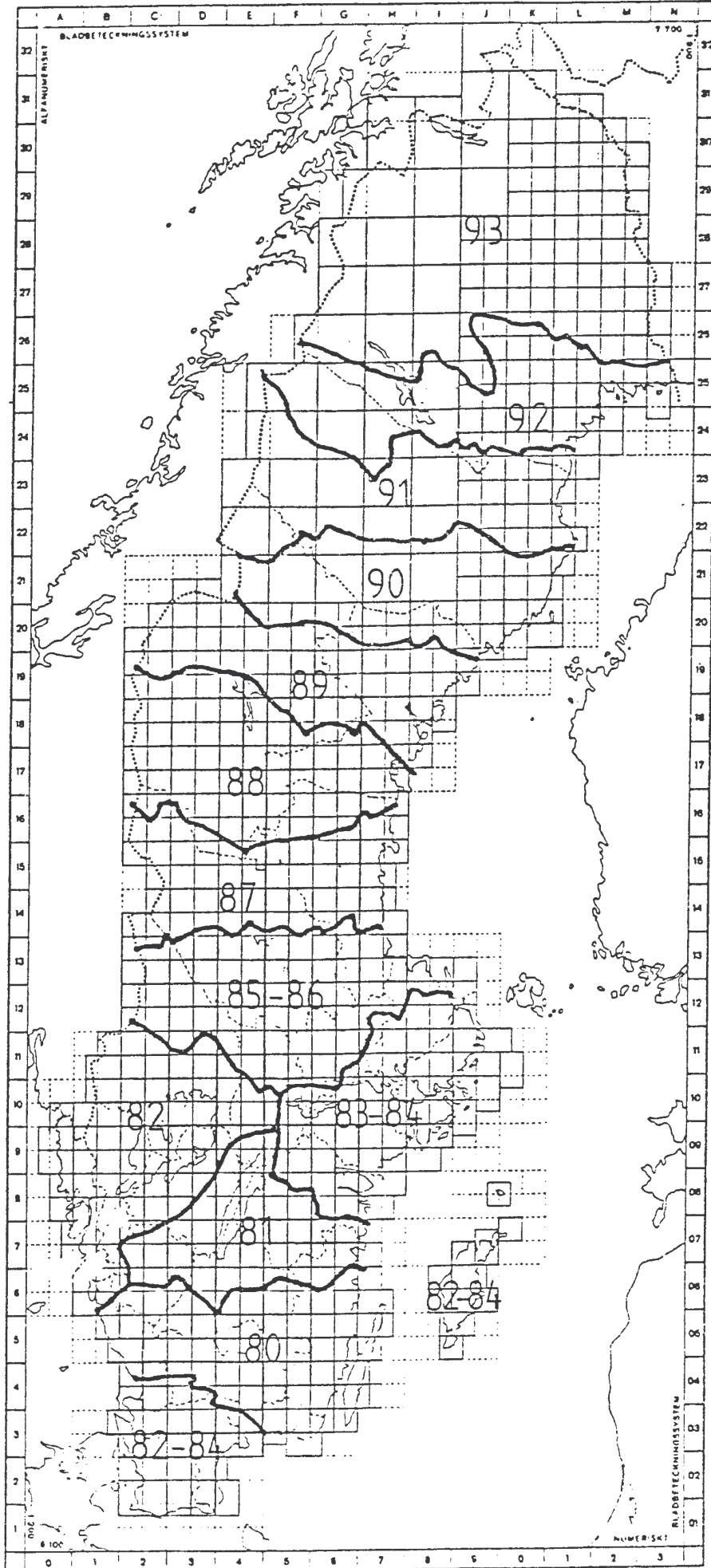
- Levelling carried out 1951 - 1966
- - - Levelling carried out 1886 - 1905
- Mareograph stations



# BLADINDELNINGSKARTA ÖVER SVERIGE

STATENS LANTMÄTERIVERK

TOPOGRAFISKA KARTAN



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Fig 2.

Planned regions with provisional figures showing planned year for levelling



Fig 3. LEVELLING IN SWEDEN: COMPARISON OF PRODUCTION FIGURES FOR 3 TYPES OF LEVELLING

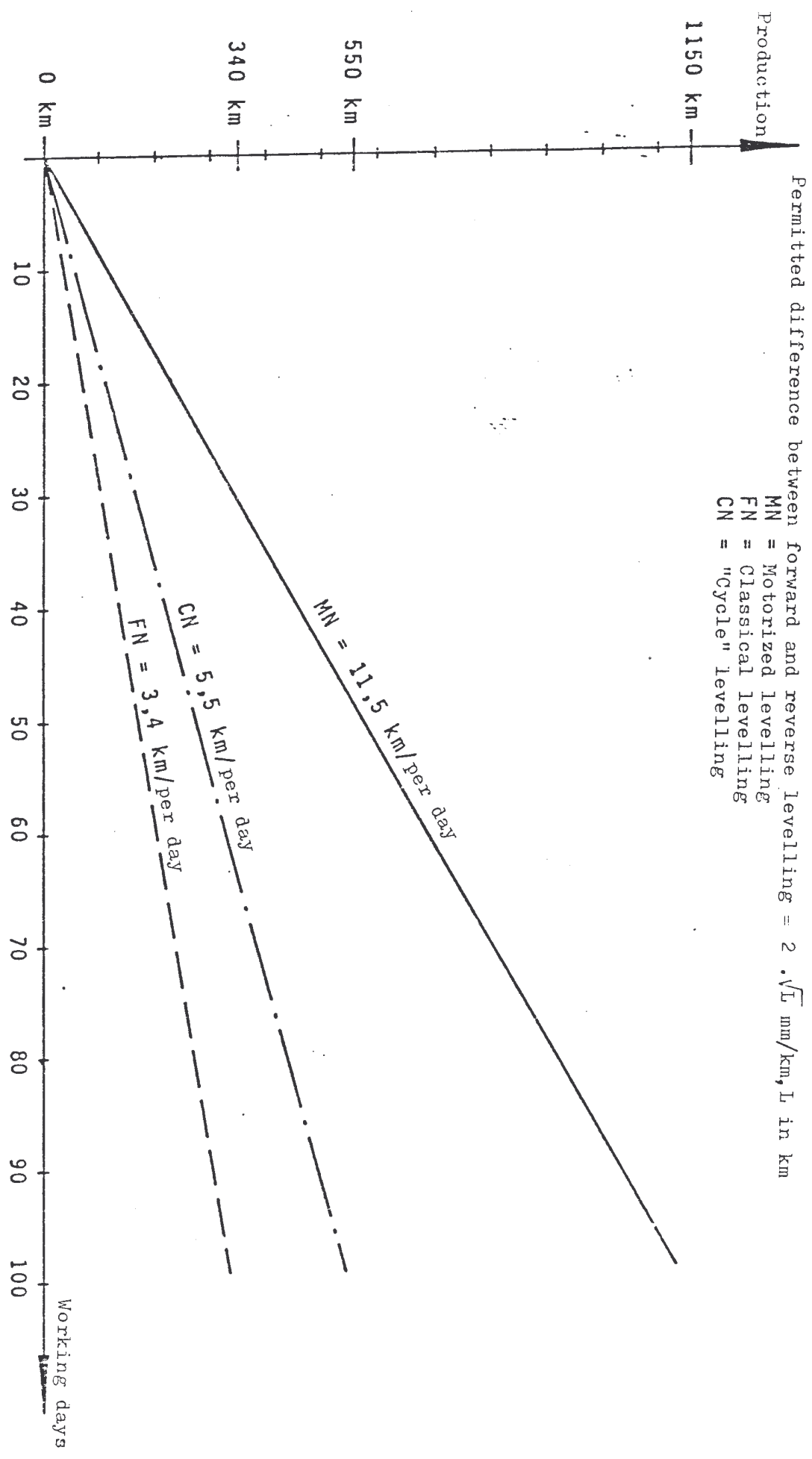


Abb. 1