Final Report

on the

Joint Test on Gross Error Detection

of

OEEPE and ISP WG III/1

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FINAL REPORT ON THE JOINT TEST ON GROSS ERROR DETECTION OF OEEPE AND ISP WG III/I

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1. Introduction

The efficiency and quality of block adjustment procedures highly depend on the applied strategy for gross error detection and on the ability to give information on the stability of the solution with respect to non-detected gross and systematic errors. Whereas the theory for handling systematic errors has reached a high and practical standard which is proved by numereous controlled tests during the last decade, there is no commonly accepted strategy nor theory for the blunder detection problem. This is due to the great variety of types of gross errors and the unability of the theory to predict the efficiency of even simple strategies in the presence of more than two or three gross errors. Thus quite some heuristics are and will be necessary to come to operational solutions of the gross error problem.

During a meeting of Commission A of OEEPE at the Hamburg ISP Congress in 1980 it was therefore proposed to start an empirical test to get information on the status of existing error detection procedures. As there was a broad interest in that test by persons from other continents, as well, it was decided to use the data also in the ISP Working Group III/I "On the Identification of Gross and Systematic Errors". The increase of the number of participants promised to give a wider spectrum of the results.

The scope of the test was twofold:

1. The first aim was to find out the present status of strategies used for error detection, especially to develop information on how efficiently large gross errors could be found.

The theories known to treat the error detection problem only concern <u>small gross errors.</u> These are errors which are just beyond the boundary to random errors, i. e. in the range between 3 and 20 times the standard deviation σ_{l_i} of the observation l_i. The theories, however, also hold for <u>medium sized gross errors</u> , which do still fall in the range of the linearization of the perspective model. Medium sized gross errors in photogrammetric application thus are smaller than half a base length, say. As <u>large gross errors</u> beyond this limit also occur and usually lead to strong deformations of the blocks or at least to quite wrong approximate values, they result in gross errors in the coefficients of the error equations, i. e. in a wrong design matrix and cannot be handled by current theories, which assume a linear relationship between the observations and the unknowns. The efficiency of an error detection procedure with respect to large gross errors thus can only be evaluated empirically.

2. The second aim of the test was to find out the sensitivity of existing error detection procedures to separate small gross errors on one hand and random and systematic errors on the other hand.

The theories known are capable of predicting the efficiency of a procedure if one single gross error or one group of gross errors and in addition only random errors are present. Even if all large and medium sized gross errors would have been eliminated and even if some self-calibrations had been applied,several small gross errors and remaining systematic errors have to be expected to be left in the data. This prevents the theories to be applicable. A realistic evaluation of a procedure, thus also in this case can only be based on proper empirical tests.

In order to achieve clear statements it was decided to split the test into phases 1 and 2 resp.. In both phases several blocks were generated with errors which were only known to the distributor (Institute for Photogrammetry, Stuttgart University). These data were distributed to the participants who cleaned the blocks using their standard procedure.

The data of phase 1 were distributed in March 1981. A preliminary report on the results was given at the Commission III Symposium of ISP in Helsinki 1982 (cf. Förstner, 1982). During a meeting of ISP WG III/I at the Photogrammetric Week 1983 in Stuttgart further results especially on the absolute accuracy were presented. The data of phase 2 were distributed in June 1983 and a preliminary report on the results was given at the ISP Congress 1984 in Rio de Janeiro (cf. Förstner, 1984).

This final report collects all the results of both phases. In addition to the two previous reports it contains a further analysis of phase 1, as it was presented at the WG-meeting 1983 and a more detailed analysis of the reactions of the participants based on the differences between the cleaned coordinates provided by the participants and the true coordinates known from the data generation.

This report is based on the work of the following organizations:

	phase 1	phase 2	Organisation
1.	x		Surveyor General, Adelaide, Australia
2.	x	x	Lands & Survey Dept., Perth, Australia
3.	x	x	National Research Council, Ottawa, Canada
4.	x	x	Laboratoriet for Fotogrammetri og Landmaling, Aalborg, Denmark
5.	x		Hunting Survey Ltd., England
6.	x	x	Institute for Photogrammetry, Helsinki, Finland
7.	x		Fachgebiet Photogrammetrie und Kartographie, Darmstadt, FRG
8.	x		Institut für Angewandte Geodäsie, Frankfurt/M., FRG
9.	x		Lehrstuhl für Photogrammetrie, München, FRG
10.	x		Technische Hogeschool, Delft, The Netherlands
11.	x	x	Rijkswaterstaat, Delft, The Netherlands
12.	x	x	ITC, Enschede, The Netherlands
13.	x		Norges Geografiske Oppmaling, Hønefoss, Norway
14.	x		Universitet i Trondheim, Norway
15.	x	x	National Land Survey, Sweden
16.	x		Institut de Photogrammetrie, Lausanne, Suisse
17.	x		Lands & Survey Department, New Zealand

2. Design of Test

The test was designed according to the following line of thought:

1. Control on detected gross errors

In order to keep control on the detected gross errors, simulated data were used. Whereas the point distribution was chosen as realistic as possible random, systematic and gross errors were artificial.

2. Types of Blocks

Blocks with bundles and with independent models were generated, both with sparse and dense tie point distribution. This was to simulate blocks for topographic mapping (I) and for point determination (II). Thus 8 blocks were generated (cf. table 1).

Table 1 Distributed blocks

Type	tie point distribution			
	sparse		dense	
	phase 1	phase 2	phase 1	phase 2
model	MI/1	MI/2	MII/1	MII/2
bundle	BI/1	BI/2	BII/1	BII/2

3. Number of Gross Errors

The number of gross errors was chosen as high as it may occur in the worst case. In phase 1 also very trivial gross errors were inserted in order to find out how sophisticated or automatic procedures behave under extreme conditions without the help of graphical plots. In phase 2 , however, only small gross errors were inserted, except for a few medium sized ones, in order to simulate the situation during the last stage of the error detection procedure.

4. Systematic Errors

All blocks, except one, contain systematic errors, either of constant size or varying from image to image but having a common mean. One block (MI/2) was not falsified by systmatic errors in order to be able to compare the empirical efficiency with the theoretical values.

5. Documentation of Strategy and Criteria for Error Detection

The participants were asked to sketch their usual strategy for error detection and to document the actual procedure used for the test data. In phase 2 this specifically concerns the criteria used for rejecting observations in order to be able to compare the empirical and the theoretical efficiency.

6. Economy

It was intended to compare the economy of the procedures used in phase 1 based on preparation time, computing time, number of runs, etc.. However, the economic aspects cannot be discussed here, because not all responses about used times were detailed enough and the individual computing conditions cannot be taken into account.

7. Estimated Size of Gross Errors

The estimated size of the gross errors compared with the true size give an indication whether the estimated size can be used for classification or even correction of the gross errors.

8. Accuracy

The accuracy of the cleaned blocks is a decisive check on the quality of the error detection procedure. Therefore the adjusted coordinates of all points are compared with the true coordinates yielding the absolute accuracy in terms of a root mean square and a maximum error. In phase 2 the participants were also asked to tell how accurate they guess the result is, in order to compare it with the empirical one.

3. Test Perfomance

3.1 Data Generation

The simulation of the data was based on the adjusted observations of a real bundle block. A subblock of the Appenweier test block was used, which containes very flat terrain. These data lead to error free coordinates of the new points and are used as a reference for the evaluation.

First two bundle blocks were generated by selecting appropriate points leading to blocks BI and BII with sparse and dense tie point distribution. The images of block BI contained at least 6 tie points in the standard positions with one excepetion.The centre tie point in image 50 in strip 4 (cf. fig. 3) is missing in all 3 images (49, 50, 51). The images of block BII contained at least 6 double points at the standard positions with the same exception as in BI. In block BI/2 of phase 2 the missing point was inserted in order to stabilize the geometry of the block in this area.

Similarily two models blocks MI and MII were generated. The models were derived from the image pairs of the two bundle blocks using an analytical relative orientation. Due to the missing point one model was missing in the 4th strip in MI/1. The blocks had 4 strips with 13 images and 12 models resp.. The sidelap was 20 %, the overlap 60 %. Thus the size of the blocks was 52 images and 48 (47) images resp..

The control point pattern was chosen accordingly. Horizontal control points were only selected at the perimeter of the blocks, being double points for the blocks with dense tie point distribution. Four chains of vertical control points were selected to stabilize the height of the blocks. Further information on the simulated blocks is collected in tables 6 and 7.

The true oberservations were contaminated by random and sytematic errors. Hints about the contamination were given to the participants (cf. tables 2 and 3).

3.1.1 Contamination of Blocks in Phase 1

The random errors in phase 1 were normally distributed.

They had constant standard deviation for blocks MI/1 and MII/1.The standard deviations in height were assumed to be a factor 1.5 larger than those in planimetry. The standard deviations of the x- and y-coordinates of the projection centres were assumed to be 3 times larger than those of the model points. The z-coordinates,however, of the projection centres had the same precision as the planimetric coordinates of the model points.These ratios are theoretical values derived from error propagation (cf. Schumpp/Ehrenfried 1981).

In block BI/1 the random errors had also constant standard deviation.

Block BII/1 was assumed to consist of two parts, strips 1 and 2 and strips 3 and 4, which were considered to be flown under different conditions (cf. table 2). Therefore the precision of the oberservations was different for the two parts of the block.

The models were deformed systematically using a second order polynomial

$$\begin{pmatrix} \underline{x} \\ \underline{y} \\ \underline{z} \end{pmatrix} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \underline{A}_1 \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \underline{A}_1 \begin{pmatrix} x & x & x \\ y & y & y \\ z & z & z \end{pmatrix} \cdot \underline{A}_2 \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

in which $\underline{A}_1$ and $\underline{A}_2$ are 3 x 3 matrices with random values.

The images were deformed systematically using a combination of Brown's and Ebner's set of additional parameters (cf. Kilpelä 1980). A representative example is given in table 4 and figure 9. The general expression of the systematic errors is given by :

```
PX=R1*SYS(1,ISYS)*X+R1*SYS(2,ISYS)*Y+R2*SYS(3,ISYS)*            }
.    ((-2.)*X2+1./R2)+R2*SYS(4,ISYS)*X*Y+R3*SYS(5,ISYS)*C         }
.    +R4*SYS(7,ISYS)*X*C+R4*SYS(9,ISYS)*Y*A+R5*SYS(11,ISYS)*A*C   }
PY=R1*SYS(1,ISYS)*(-Y)  +R1*SYS(2,ISYS)*X  +R2*SYS(3,ISYS)*X*Y+   }  (Ebner)
.    R2*SYS(4,ISYS)*((-2.)*Y2+1./R2)       +R3*SYS(6,ISYS)*A+     }
.    R4*SYS(8,ISYS)*Y*A  +R4*SYS(10,ISYS)*X*C+R5*SYS(12,ISYS)*A*C }
PXB=X/CCC*(R13*SYS(7,ISYS)*(X2-Y2)+R15*SYS(8,ISYS)*X2*Y2+          }
.    R15*SYS(9,ISYS)*(X2*X2-Y2*Y2))+X*(R16*SYS(10,ISYS)*Z4+        }
.    R17*SYS(11,ISYS)*Z8+R18*SYS(12,ISYS)*Z12)                     }  (Brown)
PYB=Y/CCC*(R13*SYS(7,ISYS)*(X2-Y2)+R15*SYS(8,ISYS)*X2*Y2+          }
.    R15*SYS(9,ISYS)*(X2*X2-Y2*Y2))+Y*(R16*SYS(10,ISYS)*Z4+        }
.    R17*SYS(11,ISYS)*Z8+R18*SYS(12,ISYS)*Z12)                     }
```

Thus the parameters p_1 to p_{12} had influence on both, Brown's and Ebner's polynomials. As it can be seen from table 4, however, the effect of Ebner's polynomials onto the systematic errors is dominating.

Due to a gross error during data generation block BII/1 contains an unusual systematic error in the control points: the z-coordinates have a different scale, namely 0.7, than the x- and y-coordinates. This error has no large influence, due to the flatness of the terrain. It has been left in the data in order to analyse its effects onto the results.

3.1.2 Contamination of Blocks in Phase 2

In contrary to phase 1 the true observations were contaminated by non-normally distributed random errors. Their distribution was a mixture of two normal distributions N:

$$F = 0.95\ N(0,\ \sigma^2) + 0.05\ N(0,\ (2\sigma)^2).$$

Thus on an average every 20th observation was assumed to have double the standard deviation than the others. The standard deviation σ was constant for all observations of each block.

All images were deformed systematically, again using a combination of Brown's and Ebner's set of additional parameters. In contrary to phase 1, however, these deformations were not block invariant. Actually the additional parameters $\underline{p}_i$ were assumed to be random variables with constant, i. e. block invariant expectation $E(\underline{p}_i)$ and standard deviation σ_{pi} . $E(\underline{p}_i)$ varied between 0 μm and $\pm$ 14 μm, σ_{pi} between 0.7 μm and 2.7 μm. They were taken and adapted from the empirical results obtained by Schroth (1982, cf. table 5). The variation of the parameters can be seen in in fig. 10 for two representative examples.

On the other hand the coordinates of the block MI/2 with sparse tie point distribution were not contaminated by systematic errors, in order to compare the efficiency of the error detection procedures more simply with theory. The systematic errors introduced into block MII/1 were constant for all models and, as in phase 1, consisted in a general deformation of 2nd degree.

3.2 Inserted Gross Errors

3.2.1 Gross Errors in Phase 1

In phase 1 the idea was to insert all kinds of gross errors occuring in practical blocks, being aware, that they do not necessarily occur simultaneously. Thus also very trivial errors were introduced:

- wrong coordinate system (change of the sign of one or two coordinate axes of control points or in parts of the block for the last case hints were given to the participants, cf. table 2);

- a missing model (see above);

- missing and wrong numbers in the sketch every particpant received.

The other errors can be subdivided into the three categories discussed above.

The large gross errors in most cases were exchanges of point numbers and wrong coordinates, errors of round values, supposed to be caused by mispunchings (e.g. 21 364.76 instead of 12 364.76 or instead of 11364.76). They were supposed to be correctable.

This partly also holds for the medium sized gross errors, whereas the small gross errors only consisted of coordinate errors (misidentifications). The blocks with dense tie point distribution gave the opportunity for groups of gross errors which are treated as one error in the analysis. The individual errors are given in tables 8 to 11 (cf. fig. 1 to 4). They will be discussed in detail in section 4.5.

3.2.2 Gross Errors in Phase 2

The idea of phase 2 was to determine the efficiency of the practical procedures to detect small gross errors. The efficiency can be described by the probability of finding an error of a given size. As known from theory gross errors can only be found if they are larger than a certain lower bound $\nabla_o l_i$. This bound depends on the precision σ_{li} ,the redundancy number r_i of the observation and on the statistical parameter δ_o which was to be assumed to be 4 in the test. It corresponds to a critical value of appr. 3 and a minimum power, i. e. efficiency of 80%. The size of the inserted gross errors is referred to the lower bound of the observation in concern.

Four types of errors were inserted into the blocks (cf. columns 2-4 in tables 12-15):

1. Small gross errors in the photogrammetric data. Their size varied between 0.7 $\nabla_o l_i$ and 2 $\nabla_o l_i$. Always 4 - 7 errors of the same type were generated to be able to estimate the empirical efficiency. Due to the different local redundancy the actual size of the errors in Δm varied within each group. The model block MII/2 with dense tie point distribution gave the opportunity for groups of gross errors which are again treated as one error in the analysis. The dense bundle block BII/2, however, was distorted with single gross errors as even adjacent points within one image do not really control each other.

2. Small gross errors in the control points. Their size varied between $1 \cdot \nabla_o l_i$ and $4 \cdot \nabla_o l_i$.

3. Medium sized gross errors upto 150 $\nabla_o l_i$. They were partly supposed to be correctable.

4. Miscellaneous errors such as point exchanges or grouped errors.

Types 3 and 4 were meant to keep the data realistic. The individual errors are given in the table 12 - 15 (cf. fig. 5 - 8).

4. Results of Phase 1

4.1 General Information

The number of distributed blocks MI/1, MII/1, BI/1 and BII/1 was 14, 10 and 10 resp. Among these 12, 10, 6 and 5 blocks resp. were sent back. The used adjustment programs may be divided into the following categories:

a) Independent Models
   - polynomial adjustment
   - iterative least squares adjustment (planimetry-height)
   - rigorous adjustment (7 parameters per model).

No self-calibration was applied. 3 programs had the facility of data-snooping techniques.

b) Bundles
   3 programs used the facility of self-calibration, one applied data-snooping techniques and one included an automatic procedure for data cleaning, adapting the weights to the residuals of the previous iteration.

One participant cleaned the photogrammetric data of block MI only. The result is not included in the following analysis. It is worth to be mentioned, however, as the strategy is a pure pre-error-detection procedure based on the test of conditions between the observations. All large gross errors were found in 6 hours of work (see preparation times section 4.4).

4.2 Strategies

It is rather difficult to compare the different strategies used by the participants. Tables 20 and 21 show the sequence of steps during error detection as they were described by the participants. There obviously exist very simple but also very sophisticated strategies. The formation of strips is a very common procedure to find initial values for the adjustment. This also holds for the bundle blocks. The strategy index I_S given in the last line is a measure for the complexity of the strategy weighting the number of different steps. It will be compared with the performance index and the number of runs.

In most cases the standard procedure for error detection was applied. Only few participants changed their strategy because of the relatively high percentage of gross errors.

4.3 Detected Gross Errors

Fig. 12 shows the reaction of each participant onto the individual errors. It will be used to determine the relative efficiency of the error detection procedure in section 4.4.2. Fig. 13 summarizes the content of fig. 12 and shows graphically how often each gross error (see table 8-11) was corrected (dark), located (dark grey), realized (light grey) or not found (white) the evaluation. Some gross errors specially large ones were easy to find, while others could not be found at all as they were too small. Both groups give poor information on the individual error detection method, but of course have influence onto the number of runs. Some gross errors were located and even corrected by one participant while at the same time were not found by another participant.This demonstrates the great variety of experience and the influence of the strategy but also proves that except for a few small gross errors all gross errors could be located. This is confirmed by the following analysis.

4.4 Efficiency

The evaluation of the performance of the error detection procedures can be based on different criteria.

a) the reaction on the gross errors (cf. fig. 12) weighting properly the reaction;

b) the number n_m of missed gross errors, i.e. the number of gross errors which were not found;

c) the number n_c of correct observations which were erroneously deleted:

d) the absolute precision of the result.

Further indicators are:

e) the use of auxiliary plots;

f) the facility of the data-snooping technique (or any equivalent test)

g) the number of runs.

We will follow three lines of thought:

1. The most robust indicator is the number of erroneous decision.

2. The relative efficiency can be based on the properly weighted reactions.

3. The absolute accuracy is decisive but not available for all participants.

4.4.1 Quality of Performance of the Error Detection Procedures

The performance is evaluated by the performance index I_p

$$I_p = n_m + n_c$$

thus giving the number of erroneous decisions.

Tables 16 - 18 give some information on the performance for each block and each participant. The results are sorted according to inceasing performance index.

Fig. 11 gives a graphical representation of n_m (upwards) and n_c (downwards). It shows that all 4 blocks could be managed, i. e. nearly all gross errors could be found. On the other hand in most cases some correct observations were erroneously eliminated.

The comparision of the number of runs (tables 16 to 18) with the performance index demonstrates that even with a small number of runs a high rate of correct decisions can be obtained, thus not necessarily many runs lead to a good result.

The best result, i.e. the lowest performance indices, are obviously obtained when data-snooping technique is applied, whereas the use of auxiliary plots seems to have little influence onto the quality of the result. Both statements have to be proved using the absolute accuracy.

There is a low positive correlation between the complexity of the strategy (I_S) and the number of runs. This suggests not to use too many different types of checks but rather to simplify the procedure. Reason for this effect might be the difficulty of separating the different steps. This is confirmed by the automatic procedure (table 18,BI/1 column 3 and BII/1 column 2) used for the bundle blocks, which only needed 3 runs to clean each of the blocks.

The results seem to demonstrate that bundle blocks are easier to handle than blocks with independent models. A reliable comparision, however, is impossible, as the number of participants who treated the bundle blocks is too small and the complexity of the errors is not comparable. On the other side as could be expected, the blocks MII/1 and BII/1 with dense point distribution could be cleaned more easily and more successfully than the blocks with sparse tie point density.

Tables 16 - 18 also give an impression of the time effort which was necessary to clean the blocks. The time for the initial preparation of the data, e. g. copying the tape on disc, changing the format, was between ½ and 18 hours. The total time for cleaning one block varied between 6 and 66 hours. The shortest time for the preparation of the different runs was achieved with the automatic error detection procedure.

4.4.2 Relative Efficiency of Error Detection Procedures in Phase 1

The relative efficiency of the detection procedures is based on the individual reactions of each participant onto each gross error. Each reaction is weighted between -3 and +5:

r	symbol	weight w_r	reaction
1	#	5	corrected
2	+	4	eliminated
3	o	3	found
4	–	0	not found
5	●	-3	wrongly corrected

Thus the 4 matrices in fig. 12 represent the weights $w_r(e, p)$ for each error e $(1,....,n_e;$ rows) and each procedure p $(p=1,....,n_p;$ columns). The total weight $\Sigma(p)$ for each procedure is:

$$\Sigma(p) = \sum_{e=1}^{n_e} w_r(e, p)$$

(e. g. ranging from 64 to 111 in MI/1). The average weight $\emptyset(p)$ is given by

$$\emptyset(p) = \Sigma(p)/n_e$$

An average weight of 4.0 which was reached by procedure 2 with MI/1 indicates that on an average all observations with gross errors were eliminated. The average values $\emptyset(p)$ are only comparable within one block as other blocks might be more simple or difficult to clean.

In order to come to a quality measure which is independent from the block and which takes the different complexity of the blocks into account, the relative efficiency E is determined. It relates the total weight $\Sigma(p)$ to the best and worst possible case and is defined as

$$E = \frac{\Sigma(p) - \min(p}{\max(p)-\min(p)}$$

and given in percent in table 19. The values min(p) and max(p) are determined as the sum over the weight of the worst and best reaction for each error resp.

$$\min(p) = \sum_{e=1}^{n_e} \underset{p}{\text{minimum}} (w_r(e,p))$$

$$\max(p) = \sum_{e=1}^{n_e} \underset{p}{\text{maximum}} (w_r(e,p)).$$

They indicate the worst and best result which in total could have been reached, if no other reactions on the individual errors than those in fig. 12 could happen.

The relative efficiency values E vary between 27 % (p=10 in MII/1) and 97 % (p=2 in BII/1). The histograms for the values E are given at the bottom of the table 19. They show that the efficiency of the different procedures varies considerably. The procedure which used data-snooping technique are indicated in dark. Obviously they reached the highest efficiency in all blocks, except in BII/1.

This can be explained by the scale error in the z-coordinates of the control points, which is not compensated by the additional parameters used in the self-calibration. The result is in full accordance with that of phase 2.

4.4.3 Absolute Accuracy of Cleaned Blocks in Phase 1

The participants were asked to send back the adjusted coordinates of the cleaned blocks which lead only to a partial reaction. The last rows of tables 16 to 18 contain the summarized results. The true errors are shown in the plots fig. 14 - 17.

The first two rows contain the mean deviations of the adjusted coordinates from the true values

$$\mu^2_{xy} = \frac{1}{n} \Sigma \; x^2 + y^2$$

$$\mu^2_{z} = \frac{1}{n} \Sigma \; y^2$$

In order to keep the values comparable only those points with

$$\sqrt{\Delta x^2 + \Delta y^2} \leq 5 \text{ m}$$

are used in the above sums.

The number of points eliminated this way is given in the second last row. The number of points which are not contained in the list of the adjusted coordinates is tabulated in the last row.
The plots of the true errors will be discussed in detail in section 4.5.

<u>Model Block M/1</u>

The best absoulte accuracy in terms of the mean deviations is reached by the three participants who also obtained the best performance index I_p.

There is a significant difference in planimetric accuracy between these three results, in terms of both mean and maximum deviations. The most reliable result, however, was obviously achieved by the two data-snooping procedures. Only one point had to be eliminated. This point had a wrong point number which only could have been found by comparision with the sketch of the block. Both results are fully satisfactory.

The other tree participants (columns 5, 8 and 9) only reached a very poor result. Over 100 points had to be eliminated. Even then quite large height errors remained in the data.

This comparision again demonstrates the wide range of efficiency of the used procedure. But the good results also show that in a block with weak geometry it is indispensible to use a testing procedure which takes into account the local geometry.

Model Block MII/1

All four participants who sent back their adjusted coordinates reached fully acceptable results. The superiority of the procedures with data-snooping essentially reveals in the maximum errors, which are significantly smaller than those of the other procedures.

Bundle Block BI/1

The evaluation of the accuracy reached in the sparse bundel blocks has to take into account whether data-snooping techniques and/or self-calibration is applied or not.

The best results are reached by participants 2 and 3 who used no data-snooping techniques but applied self-calibration. Participant 1 could not reach high accuracy, as he did not apply self-calibration. This demonstrates that data-snooping is not very effective if systematic errors are present in the data. This result will be fully confirmed by BII/1 and the blocks in phase 2.

The result of participant 5 though is not consistent as it should be the best one. 19 points, however, were eliminated which is due to the error 21 in a vertical control point which was not found (cf. fig. 16d).

Bundle Block BII/1

Block BII/1 contains the large scale error in the z-coordinates of the control points, which was not compensated by any of the normally applied additional parameters. On the other hand, as the terrain is very flat, this scale error has only limited influence. Therefore the accuracy results of this block can not be evaluated rigourously. The data-snooping (column 4) though used in conjunction with self-calibration, did not lead to the best result. Also the participant with the best performance index did not reach a fully satisfactory result, at least as far as the maximum error is concerned. The mean deviations in planimetry being 0.05 m, however, are in full agreement with theory ($\approx 2\sigma_o$. scale).

4.5 Detailed Analysis of Reactions

This section wants to discuss the reactions of the participants onto the individual errors in detail. The analysis is based on the plots of the residuals in order to visualize the effect of the decisions onto the final result (cf. fig. 14 - 17).

4.5.1 Model Block MI/1

Error No. 8

Description: Point 245 was deleted and point 248 received number 245 in all models.

Discussion

This very large error is only detectable if one uses the sketch of the block. It is not locatable in the sense, that one cannot decide whether the sketch or the data is wrong. If one, however, would use the coordinates of the plot as approximate values, one would realize that point 245 is missing. The best reaction would be to renumber the point (e.g. 1000245) and insert it into a check list. This error has no influence on the other points. It shows that it is necessary to use the plot for checking the correctness of the point numbering.

Some of the participants found this error and excluded the point from the block taking into account weakening the block in this aera (cf. fig. 14a, b, c, f).

Error No. 12

Description: The projection centre 447000 received the number 342000, leading to a wrong connection of projection centres.

Discussion

The error was found and corrected by all participants who used projection centres. Three participants (partly) did not use projection centres to stabilize the block, thus could not find this error. The reason for them to exclude the projection centres were the difficulties in cleaning the height of the block (cf. 100 m error No. 13) and probably also this large error in the projection centres. Clearly, an elimination of the projection centres from the block leads to a very instable geometry and should be avoided if possible (cf. fig. 14 d, e, f).

Error No. 13

Description: The height of the vertical control point was changed by 100 m.

Discussion

This is a medium sized gross errors, as it is only 20 times larger than the boundary value $\nabla_o l_i$ of just detectable errors. This error was found and usually corrected in case projection centres were used. In 2 of the 3 cases where projection centres were not used, this error was not detected. In this case the influence on the result was formidable (cf. fig. 14e, 14f).

Error No. 15

Description: The vertical control points 23 and 62 were exchanged.

Discussion:

Due to the small height difference of ∇l_i = 0.5 m = 5 σ_H this error is not detectable. It can be treated as a random error.

Error No. 16

Description: Error of 200 μm in x in border tie point TP 2 No. 509 in model 577/573.

Discussion:

This error was inserted as it produces a larger residual at another point (No. 83). The error was,however, located correctly or not found at all. Its influence on the result is too small to be seen in case other errors are present.

Error No. 18

Description: The y-coordinate of horizontal control point No. 443 was changed from ...75 m into ... 57 m.

Discussion

This error of 18 m is a small gross error as it is only 3 times the boundary value. The redundancy number is r_i = 0.05 leading a residual of approx. 1 m. This is too small, comapred with the precision σ_{xy} = 0.5 m to be suspicious. Only two participants found this error and corrected it (exchange of digits). They used data-snooping technique. Clearly the influence of the gross error onto the result is heavy. About a quarter of the block, the aera until the next control point, is distorted (cf. fig. 14a, 14e).

This probably is the best demonstration of the effectiveness of a statistical test which takes the local geometry into account. It shows the necessity to apply such a test in areas of weak geometry.

Error No. 20

Description: Both the x- and the y-coordinate of fourfold tie point No. 203 in the middle of the block in model 447/443 was changed by 150 µm each.

Discussion

This small gross error ($3 \nabla_0 l_i$) in an aera with good local geometry ($r_i \approx 0.3$). Only two participants did not find it. As the residual $v_x \approx 1.5$ m in x-direction was approx. 5 times larger than the mean residual $\sigma_v \approx 0.3$ m this error was detectable without rigourous test (provided that the larger errors had been found). The effect of the error is too small to be seen in the plots.

Error No. 21

Desription: The z-coordinate of vertical control point No. 338 lying in the middle of the block was changed from ... 17 m to ... 71 m.

Discussion:

This middle sized gross error ($10\ \nabla_0 l_i$) of 54 m was found by all participants except one. 4 participants eliminated the point, accepting a weaker geometry. One of those who corrected this error (exchange of digits) introduced an error of 4 m. He corrected the height by 50 m instead of by 54 m. The precision $\sigma_{\widehat{\nabla l}}$ of the estimated size $\widehat{\nabla l} = -v_i/r_i$ of the gross error is only $\sigma_{\widehat{\nabla l}} = \sigma_l \sqrt{r_i} \approx 1{,}5$, ($r_i \approx .13$). Thus it would be safer to eliminate the point or renumber it and insert it into a check list for further investigation than to correct it without any check whether it is correct and to assume an exchange of digits. Its influence (cf. fig. 14f) cannot be separated from the influence of other errors.

Error No. 22

Description: The x-coordinate of horizontal control point 32, being measured only in one model, was changed by 6 m.

Discussion

This is a small gross error with ($1.5\ \nabla_0 l_i$). Four participants detected it. One participant using data-snooping eliminated the point. The other participants using data-snooping corrected the coordinate by a wrong amount, 5 m instead of 6 m. Also in this case the estimated size is too inaccurate to be useful for a classification of the error. The other two participants, however, found the error without data-snooping and corrected it. One of them used Schut's polynomial block adjustment program. The influence of the error covers the area of the block unil the next control points (cf. fig. 14a and 14 b).

Error No. 23

Description: The x-coordinate of double tie point No. 506 in the middle of strip 3 was changed by 60 µm.

Discussion:

This is a small gross error equal to the boundary value of just detectable errors. The geometry is good ($r_i \approx 0.3$). Only 2 participants detected this error, one of them with data-snooping. The other participant who used data-snooping did not find this error. The influence of the error is to small to be visualized.

Error No. 24

Description: The x- and y-coordinates of fourfold tie point No. 104 in the middle of the block was changed by 150 µm each.

Discussion:

This small gross error ($3 \cdot \nabla_0 l_i$) was found by half of the participants due to the good geometry ($r_i \approx 0.3$). Its influence cannot be visualized as it is hidden by larger errors.

Error No. 25

Description: The x- and y-coordinates of a fourfold tie point (No. 146 in model 349/346) in the middle of the block was changed by 100 µm each.

Discussion:

The reaction on this small error ($2 \cdot \nabla_0 l_i$) was the same as on error No. 24.

The same holds for **Error No. 27** ($1 \cdot \nabla_0 l_i$).

Error No. 28

Description: The x-coordinate of tie point 239 at the border of the block (model 172/169) was changed by 600 µm.

Discussion:

This medium sized gross error ($5 \nabla_0 l_i$) was found by only five participants, probably because of the poor local geometry ($r_i \approx 0.10$). The influence though clearly visible (cf. fig 14d) is only of local character.

4.5.2 Model Block MII/1

Error No. 7

Description: The coordinates of the horizontal control points No. 32 and No. 35 were changed by $\nabla x = 20$ m and $\nabla y = -90$ m.

Discussion

The geometry of this medium sized error $(10 \cdot \nabla_{o} l_{i})$ is weak ($r_i \approx 1/8$). Only one participant did not detect the error. Instead he eliminated the connection between the models 588/584 and 584/580, namely the points 83 and 80. The influence, however, is only local (cf. fig. 15 d).

Error No. 13

Description: The x-coordinate of tie point No. 233 in model 352/356 in the middle of strip 2 was changed by 900 µm.

Discussion:

This medium sized error $(20 \cdot \nabla_{o} l_{i})$ in good geometry was found by all participants. But it was partly corrected in the wrong model. This error is not locatable. Its influence is only local (cf. fig. 15 a).

Error No. 18

Description: The z-coordinates of a point pair (No. 128 and No. 131) in model 584/581 in the middle of a border strip were changed by $\nabla z = 200$ µm.

Discussion:

This small error $(2 \cdot \nabla_{o} l_{i})$ in good geometry was found by 7 participants out of 10. Its influence is only local (cf. fig. 15a) and only in z! Even the neighbour point is not influenced.

Error No. 19

Description: The y-coordinate of tie point 98 in model 473/469 in the middle of a strip was changed by 70 µm.

Discussion:

Only 3 participants found this small gross error ($3 \cdot \nabla_0 l_i$) in good geometry. Its influence is small and local (cf. fig. 15 e).

The same holds for **Error No. 22** with only small influence ($\bar{\delta}=3$).

Error No. 23

Description: The x-coordinate of the projection centre 33400 was changed by 300 µm.

Discussion:

This is small gross error ($3 \cdot \nabla_0 l_i$) in good geometry (r_i = ¼) Only 3 participants detected, one even corrected it Due to its negligible influence (δ = 2) it is not visible.

Error No. 24

Description: The x- and y-coordinate of a fourfold tie point in the corner of a model (No. 236 in model 195/192) was changed by 100 µm each.

Discussion:

This small gross error ($4 \cdot \nabla_0 l_i$) was found by half of the participants. Its influence is only small (cf. fig. 15a,e).

Error No. 25

Description: The numbers of 869, 872 and 875 were changed to 872, 875 and 881 in all models.

Discussion:

As error No. 8 in MI/1 this error is a difference between sketch and data. Though the point group can be found to be erroneous, one cannot decide whether the sketch or the data are wrong. The best reaction would be to renumber the points (1000869 etc.) and put them into a check list for further investigation. This error again shows the necessity to use the sketch as a control. A point numbering scheme would not help much in this case.

4.5.3 Bundle Block BI/1

Error No. 8

Description: The x-coordinate of 3-fold tie point 56 in image 23 was changed by 270 μm.

Discussion:

This small gross error ($3 \cdot \nabla_0 l_i$) in the middle of a strip ($r_i \approx 1/6$) is not locatable. Though all participants found it, two of them dceided wrong (cf. fig. 16b and c). The influence onto the result is local but clearly visible, the effect ($\nabla X = 2.6$ m, $\nabla Z = 3.9$ m) is large compared to the precision of 0.15 m.

Error No. 11

Description: The 3-fold tie point 14 in image 54 at the border of the block was changed by 70 μm and 50 μm in x and y.

Discussion

This small gross error ($1 \cdot \nabla_0 l_i$) in weak geometry ($r_i = 0.08$) was not deteced by anybody. Its influence cannot be seen due to Error No. 21.

Error No. 12

Description: Both coordinates of 3-fold tie point 46 in image 51 in the interior of the block was changed by 60 μm each.

Discussion

This small gross error ($2 \cdot \nabla_0 l_i$) was not found by two participants. These two were the only ones who did not apply self-calibration. Thus the introduction of additional parameters was decisive for detecting this error. The influence onto the result is visible (compare fig. 16b with 16c), though larger errors are present in the neighbourhood.

Error No. 13

Description: The height of vertical control point 8 was changed by 2.5 m.

Discussion

This is a small gross error ($<2 \cdot \nabla_0 l_i$) though it is 25 times the standard deviation σ_x = 0.1 m. Only one participant detected this error during the check of the strip connections. The effect is clearly visible.

Error No. 17

Description: The coordinates of horizontal control point 136 at the border of the block was changed by ½ m each.

Discussion

This small gross error ($4 \cdot \nabla_0 l_i$) was only detected by one participant during strip connection. Its influence is clearly visible and leads to a distortion of a part of the block until the next (correct) group of control points. Compare figures 16a, b, c with fig. 16d in the upper right corner of the block!

Error No. 21

Description: Vertical control point was changed by 98.5 m.

Discussion

This medium sized error was detected by all participants except one. But it was interpreted as a 100 m-error and the height was changed accordingly. Thus an error of 1.5 m = 15 σ_z was introduced. It effects a larger part of the block and is clearly visible. This error again demonstrates the danger of corrections of observations, in case no proof for the classification of the error is available.

Systematic Errors

Two out of six participants applied self-calibration. In comparing fig. 16 g where no self-calibration was applied with fig. 16 c (with self-calibration) the effect of additional parameters in the right part of the block is clearly visible. The differences are up to 1.2 m which is too large compared with the precision of σ_{xy} = 0.1 m to be acceptable.

4.5.4 Bundle Block BII/1:

Error No. 11

<u>Description:</u> The y-coordinate of 3-fold tie point 29 in image 54 in the middle of strip 4 was changed by 20 µm.

<u>Discussion</u>

This small gross error ($2 \cdot \nabla_0 l_i$) in good geometry (concerning y) was not detected by anybody. Its influence is local but clearly visible (cf. fig. 17 c).

Error No. 12

<u>Discription:</u> The x-coordinate of 3-fold tie point 117 in 50 in the midel of strip 4 was changed by 60 µm.

<u>Discussion</u>

This is the coplementary error to error no. 11. It is a small gross error ($2 \cdot \nabla_0 l_i$) in weak geometry ($r_i < 0.1$) and was only detected by one participant. Its influence is local in x and z and clearly visible.

Error No. 13

<u>Description:</u> All coordinates of full control point 19 were changed by .10 m to 0.20 m.

<u>Discussion</u>

The small gross error ($2 \cdot \nabla_0 l_i$) in moderate geometry ($r_i \approx 1/6$) was found by three participants. The use of additional parameters was no guarantee for detecting this error (cf. fig. 17d). Its influence is local and clearly visible.

Error No. 15

Discription: The x- and y-coordinates of points 219, 220 and 221 were changed by 150 μm and 30 μm in images 34, 35 and 36.

Discussion

This small error in point transfer was found by three participants. The reaction was not always clear. A location of the strip where the error occured is not possible. Thus, it would have been the safest to renumber the points in both strips. Wrong decisions lead to large local influences of 0.7 m (σ_{xy} = 2 cm, cf. fig. 17 c).

Error No. 16

Description: The x- and the y-coordinate of 3-fold tie point 122 in image 22 was changed by 120 and 20 μm.

Discussion

This is a small gross error ($1 \cdot \nabla_0 l_i$) in x and y. As it is actually too small in y to be detectable, the total error cannot be localized. Three participants found it. Its influence is local and clearly visible.

Error No. 17

Description: Points 152 and 153 were exchanged in images 20, 21 and 22 of strip 2.

Discussion

The strip where the point exchange occured cannot be localized. Only one participant, however, did not correct the error in the right way. The effect is local and clearly visible (cf. fig. 17d).

Errors No. 18, 19, 20, 21

These are all small gross errors which were located by 2 or 3 participants. The effect onto the result is only visible in case the geometry is weak ($r_i \leq 0.1$, error no. 18 and 19). Otherwise the effect of the non-detected errors is negligible.

Systematic Errors

Due to large systematic errors in the height of the vertical control points the effect of self-calibration onto the absolute accuracy cannot be seen in the plots.

4.6 Best Results in Phase 1

The following list contains the participants who succeeded best in cleaning the blocks in phase 1.The performance index I_p giving the total number of wrong decision, the relative efficiency E and - as far as available - the absolute accuracy are used as criteria.

Model Block MI/1

The best results with respect to performance and efficiency were reached by the Technische Hoogeschool, Delft, the Netherlands (I_p = 6, E = 93 %). They used data-snooping technique and reached the best precision (μ_{xy} = 0.53 m, μ_y = 1.0 m). Nearly the same quality (I_p = 7, E = 79 %) was reached by the Rijkswaterstaat, Delft, the Netherlands. They needed only 7 runs to clean the blocks (μ_{xy} = 0.75 m, μ_z = 1.1 m). The best result achieved without rigourous test was submitted by the Lands & Survey Department, Perth, Australia (I_p = 11, E = 68 %, μ_{xy} = 1.5 m, μ_z = 1.0 m).

Model Block MII/1

The best result with respect to performance and efficiency was reached by the Rijkswaterstaat, Delft, Netherlands. They only missed one error and thus reached a performance index I_p = 1 (E = 87 %). The same precision (σ_{xy} = 0.13, $\sigma_z \approx$ 0.15 m) was also reached by tow other participants (Land & Survey Department, Perth, Australia and National Land Survey, Sweden). The second best performance index (I_p = 4) was obtained by the Norges Geografiske Oppmaling, Hønefoss, Norway without data-snooping (E = 63 %). They needed only 6 runs to clean the block. A better efficiency (E = 70 %) but less performance (I_p = 7) was reached by the Institute for Applied Geodesy, Frankfurt, FRG.

Bundle Block BI/1

The best result with respect to performance was obtained by the National Research Council, Ottawa, Canada. (I_p = 5, E = 58 %, μ_{xy} = 0.36 m, μ_z = 0.61 m). The highest efficiency was reached by the Lehrstuhl für Photogrammetrie, Munich University (I_p = 8, E = 78 %).Both participants applied data-snooping. The best result with respect to precision were obtained by the Land & Survey Department, Perth, Australia (μ_{xy} = 0.27 m, μ_z = 0.53 m) and the Laboratoriet for Fotogrammetri og Landmaling, Aalborg, Denmark. Both did not use rigourous tests. Aalborg applied an automatic procedure and needed only 3 runs to clean the blocks.

Bundel Block BII/1

The best result regarding performance was reached by the Institute for Photogrammetry, Helsinki, Finnland (I_p = 5, E = 57 %). They reached the best precision (μ_{xy} = 0.05 m, μ_z = 0.16 m) without data-snooping. The same precision was obtained by the Land & Survey Department, Perth, Australia. The highest efficiency was reached by the Laboratoriet for Fotogrammetri og Landmaling, Aalborg, Denmark (I_p = 7, E = 97 %) who also did not use data-snooping.The results again were obtained in only 3 runs by using automatic procedure.

4.7 Conclusions from Phase 1

The results obtained from phase 1 can be summarized as follows:

- In order to grasp large gross errors, pre-error detection procedures seem to be necessary . On-line procedures, strip formation or automatic checks of condition may be used. The separate checking of photogrammetric observations and ground control is recommendable at this stage. In order to get a link to automatic procedures the weights of bad observations may be reduced as well in this step.

- Data-snooping technique or any equivalent test, which takes the local geometry into account, improves absolute performance, efficiency and absolute accuracy. The application of self-calibration seems to be necessary to exploit the power of rigourous tests.

- The sketch of the block is necessary to detect numbering errors correctly, especially those which do not lead to discrepancies in the block adjustment.

- The reaction on gross errors should carefully be tuned to the information available. The correction of errors can be based on the sketch if it is correct or on additional information. Coordinates should not be corrected unless the type of the error can be checked independently. The precision of the estimated size of an error depends also on the local geometry and is usually 2 to 5 times worse than the measuring precision. Only medium sized gross errors and large gross errors can be classified based on the estimated size of the error.

- Automatic procedures have shown to speed up the process considerably, especially by reducing the number of runs. Weighting down bad observations seem to be the appropriate was as errouneously deleted correct observations are reintrodurces automatically into the adjustment. The weighting may be based on the residuals if a statistical test is not available.

5. Results of Phase 2

5.1 General Information

The result of phase 2 is based on 18 blocks; 5 MI/2, 5 MII/2, 4 BI/2 and BII/2. The used programs may be subdivided into the following categories:

A. Independent models

- check of model connections only
- rigorous strip adjustment only
- iterative least squares block adjustment (planimetry-height)
- rigorous block adjustment.

Only one program compensated for systematic errors using an analysis of the residuals. Only one program did <u>not</u> use data-snooping technique. One program included an automatic procedure for data cleaning adapting the weights to the residuals of the previous iteration (cf. table 26a).

B. Bundles

All programs have applied self-calibration with 9-12 additional parameters. Two programs used the facility of data-snooping technique. One program included an automatic procedure for data cleaning adapting the weights to the residuals of the previous iteration (cf. table 26b).

5.2 Detected Gross Errors

Tables 22-25 show the reaction of the individual participants on each gross error introduced into the data. Specifically the estimated size of the error and the evaluation of the response is given.

In all cases, except those denoted by the minus sign "-", it is assumed that the error was found. Scanning for the different symbols the following statements can be made:

\# **The error was found, correctly located and corrected.** Only few small gross errors were corrected.

y **The error was found, correctly located but corrected by a wrong amount.** Quite some errors were introduced by the participants using a weak estimation of the size of gross errors. A comparision of the estimated and the true sizes of the errors clearly shows that there is no real chance to get a reliable basis for error correction in case of small gross error. This is in full agreement with the theory as the standard deviation of the estimated size $\hat{\nabla l_i}$ of the errors never is better than the precision of the observation, on an average it is 2 - 5 times larger. Only for medium sized gross errors the relative accuracy of the estimated size is high enough to draw reliable conclusions (cf. phase 1).

\+ **The error was found, correctly located and the observation(s) was (were) eliminated.** The sign is only given for reactions which are correct and justified, i. e. if there is a reason for the decision. Wrong tie points lying in 2 models or tie points with a non-acceptable x-parallax lying in 3 images had to be eliminated completely. Otherwise the reaction was correct by chance (→0), used the non-ideal geometry of the strip (+!) or was made arbitrarily (→0¹) being aware of the possibility to commit an erroneous decision.

o **The error was found but not correctly located.** This situation mainly occured at the above mentioned points in 2 models or 3 images but also at control points.

? **In this case the reaction was not quite clearly described.** For the analysis it was assumed that this error was found.

x **Only one of the errors within a group of errors was found.**

There are quite some gross errors where all participants reacted the same way. Thus, with respect to these errors the stategies, namly testing the residuals or applying a rigorous test, are equivalent. On the other hand there are gross errors which were not found by one participants but correctly located by another. A comparison of the reactions to the errors in the models (cf. tables 22 and 23) suggests strategies 4 and 5 to be superior to the others while mutually showing minor differences. Concerning the model blocks, however, participant 4 was the only one who did not use a statistical test (cf. table 26a). This suggests data-snooping in practice not beeing as effective as to be expected from theory and seems to contradict the results of phase 1 where strategies with data-snooping showed to be superior to strategies without rigorous test.

However, participant 5 used a-priori σ_o-values for the data-snooping test, which were about a factor 2 larger (σ_{xy} = 10 μm, σ_z = 15 μm for the photogrammetric points) than the theoretical values (cf. table 6).

These were appropriate for MI/1 but clearly prevent the detection of small gross errors, especially in MII/2. (cf. errors No. 9, 10, 17, 20, 21, table 23). On the other hand participant 5 was the only one who found some of the gross errors in the projection centres (2 out of 3) in MII/2 which is due to the assumed standard deviation of the projection centres (σ_{xy} = 20 μm) which is close to the value from the simulation (σ_{xy} = 24 μm).

The reaction on the bundle blocks also do not show a clear pre-dominance of the procedures with data-snooping. This may be explained by the variation of the systematic errors which cannot fully be compensated by the applied self-calibration techniques. The remaining systematic errors seem to prevent the statistical tests to show their power.

The performances indices I_p show the same tendencies (cf. table 26).

As the gross errors were small and wrong decisions might have only little influence on the final result we will not discuss the performance index but rather analyse the power of the tests and the obtained absolute accuracy.

5.3 Efficiency

The efficiency of the procedure is estimated from the results listed in tables 22-25. Table 26 contains the probabilities with which the gross errors of different sizes were found by the participants. The extreme values (min, max) and the average values (Ø) of these probabilities are shown in fig.18.

The efficiency or power of a test depends on the size l_i of the gross error and is set into realtion to the lower bound $_o l_i$. Theoretically gross errors of this size can be found with a probability of approximately 80 % if a statistical test with a critical value of 3.3 (corresponding to a significance level of 99.9 %) is used. The probability of detecting larger errors increases, smaller errors can be found with a lower probability. In fig. 18 the theoretical efficiency is represented by the smooth curve.

The comparision of the empirical and the theoretical efficiency for model block MI/2 shows that the power of practical error detection procedures can be predicted quite reliably. The maximum values for the efficiency are not reached by the same participant (namely 4 and 5, cf. sec. 5.2). The minimum values are reached by the strip adjustment control.

The proximity of the empirical findings to the theoretical values is mainly due to the absence of any systematic errors in MI/2. This is proved by the block with systematic errors where no self-calibration was applied in all cases.

The results of the bundle block confirm this as the empirical and the theoretical efficiency do not differ so much as for MI/2. The empirical and the theoretical curves have a similar shape. The self-calibration applied in all 4 cases obviously was capable to compensate parts of the systematic errors. Remember, that the systematic errors are varying from image to image leaving at least rests of the image deformations in the data. The results from BII/2 are closer to the theoretical expectation than those of BI/2 probably because of the higher stability of the block BII/2 which allows a more reliable determination of the additional parameters.

If one would use an average of the estimated σ_0-values instead of the true value for determing the theoretical efficiency the difference to the empirical efficiency would become negligible, suggesting that the uncompensated sytematic errors are the main source for the reduced power of the error detection procedures. Again, there seems to be no significant difference between those procedures which use a rigorous test and those which rely in the analysis of the residuals.

5.4 Absolute Accuracy

The absolute accuracy of the cleaned blocks can be determined by comparing the adjusted with the true coordinates. Table 27 contains the maximum ε and the r.m.s errors μ for the bundle blocks including also the estimates $\hat{\mu}$ for the accuracy and the empirical precision $\hat{\sigma}_0$ of the image coordinates provided by the participants.

The maximum errors obtained by the 4 participants for the bundle blocks are nearly identical suggesting the results to be of similar quality. This actually is true for the planimetry (μ_{xy}) but not for the heights (μ_z), especially for BI/2 where the r.m.s. errors vary up to a factor 3. (The columns in table 27 are sorted according to the achieved absolute accuracy.) The absolute values are also very high if one takes the scales 1 : 15 000 and 1 : 3 000 for BI/2 and BII/2 resp. and the precision ($\hat{\sigma}_o$) into account. This is confirmed by the optimistic estimates $\hat{\mu}$ for the absolute accuracy given by the participants. The actual r.m.s.e. prove to be at least a factor 2 (up to a factor 10) larger than presumed. The maximum discrepancies on an average are also larger than one would expect from pure error propagation ranging up to 6 times the r.m.s.e. values μ. This is due to undetected small gross errors, specifically errors in the x-coordinates of points lying only in three images. This proves the external reliability measures ($\bar{\delta}_o \cdot \sigma_x$) to be a useful approximation for the maximum error in the result of an adjustment.

5.5 Detailed Analysis of Reactions on Bundle Blocks

As for the model blocks we discuss the reactions of the participants onto the individual errors in detail based on the plots of the true errors (cf. fig. 19 and 20).

5.5.1 Bundle Block BI/2

Error No. 4

Description: The x-coordinates of points 138 and 152 in image 34 were changed by 100 μm.

Discussion:

This is a group of small not locatable errors. Only one of both errors was found by the participants. The effect ($\nabla Z \approx 2$ m) of the remaining error is local and clearly visible.

Error No. 6

Description: The x-coordinate of 3-fold tie point 90 in image 18 was changed by 70 μm.

Discussion:

This small gross error ($2 \cdot \nabla_o l_i$) theoretically cannot be localized. Two participants eliminated the correct point, one by chance. The others obviously used the y-parallaxes for localization due to the non ideal geometry. The effect ($\nabla Z \approx 1$ m) is local.

Error No. 17

Description: The x-coordinate of 3-fold tie point 81 in image 45 at the border of the block was changed by 70 μm.

Discussion:

This small gross error ($1.3 \cdot \nabla_o l_i$) in weak geometry ($r_i \approx 0.08$) was not found at all. Its local effect ($\nabla Z \approx 1$ m) is clearly visible.

Error No. 21

Description: The x-coordinate of 3-fold tie point 46 in image 52 was changed by 52 µm.

Discussion:

The reactions on this small error (1.6 ' $\nabla_0 l_i$) were similar as on the previous error. All found it but only two located it correctly. The effect onto the result is masked by error no. 27.

The same holds for **Error No. 23.**

Error No. 27

Description: Vertical control point 38 at the border of the block was changed by 1.8 m.

Discussion:

This is a small gross error (2 '$\nabla_0 l_i$) in weak geometry (r_i<0.1)and was found by two participants. One of them applied data snooping but corrected the height by a wrong amount (4 m). The estimate (2.4 m) of the other participant shows that it is not precise enough to be a hint for the true size of the error.

Error No. 28

Description: The horizontal control point 44 at the border of the block was changed by 1.2 m.

Discussion:

Only one participant found this small error (2 ' $\nabla_0 l_i$) using data-snooping technique. Again he corrected the coordinate by a wrong amount (0.8 m) in the wrong coordinate (Z). The patterns (fig. 19 a vs. 19 b, c, d) show the different effect of the reaction.

Error No. 29

Description: Vertical control point 142 in the middle of the block was changed by 3 m.

Discussion:

This small gross error $(4 \cdot \nabla_0 l_i)$ was found by three out of four participants. One corrected it the right way. Another estimate of the size of the error (2 m),however, shows the weakness of this value. Surprisingly the 4th participant who did not find this error applied data-snooping. This error distorts half of the block heavily (cf. fig. 19 a).

Error No. 30

Description: Horizontal control point 73 at the border of the block was changed by 1.5 m in Y.

Discussion:

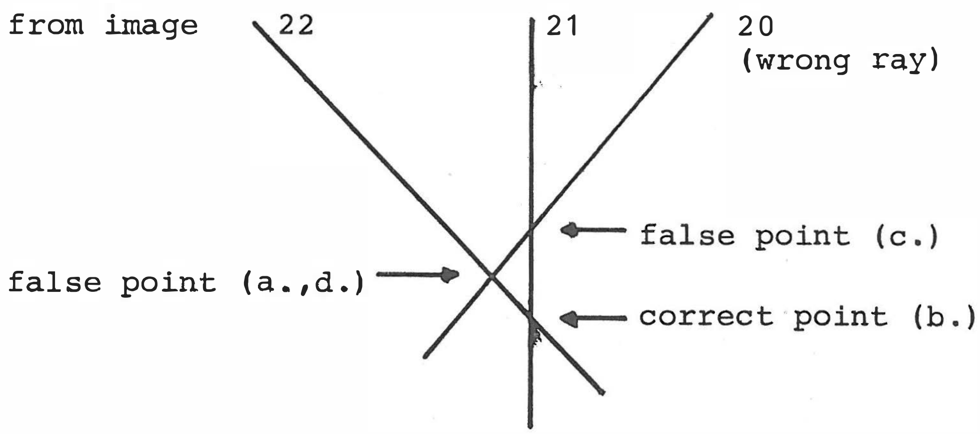
Only one participant reacted correctly onto this small gross error $(4 \cdot \nabla_0 l_i)$ and eliminated the point. One other participant found it but corrected the coordinate by a wrong amount. The effect of the non-detected error onto the block is large,specifically the largest influence is not at the wrong point.

Error No. 33

Description: The x-coordinate of 3-fold tie point 77 in image 20 was changed by 1 000 μm.

Discussion:

Only one participant reacted correctly onto this medium sized gross error, which is not locatable. He eliminated this point completely (cf. fig. 19 b). The other three located the blunder incorrectly and eliminated the wrong point. Two of them eliminated the point with the largest residual, i. e. the point in the middle image no. 21. The other participant though beeing aware to possibly reject an error free observation, deleted the point in image 22. The effect of this decision can be clearly seen in fig. 19 a, c and d. It can be visualized by the intersection of the 3 rays:



5.5.2 Bundle Block BII/2

Error No. 26

Description: Vertical control points 25 and 26 in a corner of the block were changed by 2 m.

Discussion

This small gross error ($2 \cdot \nabla_0 l_i$) was not found by any participant. It effects only a local aera of the block until the next groups of vertical control points (cf. fig. 20).

Error No. 32

Description: The x-coordinate of 3-fold tie points 136 and 137 were changed by 120 µm.

Discussion:

This group of small gross errors was found by all participants. Two, however, did not eliminate the point. One of the others eliminated the right one by chance. The effect is local and clearly visible (cf. fig. 20 d).

A similar reaction can be observed for **error no. 33.**

Error No. 34

Description: Four-fold tie point 190 at the border of the block was changed by 1 000 µm in each coordinate in images 5 and 18.

Discussion:

This is a point transfer error which is not locatable in the sense that one cannot decide in which of the two image pairs 5/18 or 6/19 the error occured. All participants found this error. One chose the wrong image pair. The effect is local and clearly visible (cf. fig. 19 c).

5.6 Discussion of Phase 2

Phase 2 of the test specifically was designed to evaluate the adjustment procedures with respect to small gross and systematic errors. Due to the absence of large gross errors, quite a percentage of non-detectable errors and the small number of participants the results of the second phase do not vary to such an extent as those of phase 1.
There are three aspects which, however, are of special interest.

1. Data-snooping which showed its power in phase 1 did not reveal to be dominant in phase two. Besides the reasons mentioned above, this might result from the variation of the systematic errors introduced in the bundle blocks in phase 2. In addition, the correct estimation of σ_0 seems to be essential for a statistical test to be able to graps the small errors.

2. This leads to the second aspect. The precision of the results was consistently overestimated at least by a factor 2. The variation of the systematic errors and possibly also the effect of non-detected gross errors seem to be the reasons.

3. Provided a realistic σ_0 is available the efficiency, i. e. the probability of detecting gross errors can be reliably derived from theory. This clear (though visual) confirmation could not be expected from the beginning and shows the importance to take into account the geometry of the adjustment as far as possible.

The other results of phase 2 are in agreement with the conclusion from phase 1 and are not discussed here again.

6. Conclusions and Recommendations

The result of this empirical test gives a clear picture of the status of exisitng error detection procedures. The classical procedures which rely solely on the analysis of the residuals without taking into account the local geometry of the block are capable to produce coordinates of a high quality provided the data cleaning is done by skilled personnal and with care. The implementation of rigorous tests is helpful for the localization of even medium sized gross errors and in extreme cases for the detection of gross errors which are hardly larger than the lower bounds for detectable errors. There is, however, no evidence that in photogrammetric blocks with a more or less regular shape rigorous tests would improve the results significantly nor that statistical methods might be a surrogate for experience. Only for irregular shaped blocks with weak control the local geometry must be taken into account which then will of course document the instability of the block.

The following recommendations can be derived from the analysis of the test:

- Pre-adjustment error detection procedures are necessary to grasp large gross errors. On-line procedures, strip formation or automatic checks of conditions may be used to advantage. The separate checking of photogrammetric observations and ground control is recommendable at this stage (phase 1).

- Automatic elimination of observations reduces the number of runs considerably. Weighting down bad observations seems to be the appropriate way, as erroneously deleted correct observations are reintroduced automatically into the adjustment. The weighting may be based on the residuals, if the local redundancy is not available (phase 1).

- A statistical test (e. g. data-snooping) in general leads to the best results with respect to the localization of medium sized gross errors and the detection of small gross errors.

- A plot of the residuals, though not necessary for the detection of observational errors, seems to be useful for the detection of numbering errors, especially those which dot not have an influence onto the residuals. It will depend on the local facilities how the information of the sketch of a block can be utilized for error detection.

- Observations should only be corrected if the error can be identified based on listings etc. or if point numbers are evidently wrong. The size of a gross error estimated from an adjustment is inaccurate up to several times the standard deviation of the observation and therefore can only be used for the classification of medium sized gross errors (larger 1 mm at image scale; phases 1 and 2).

- If gross errors are <u>not locatable</u> the whole point should be taken out of the adjustment or appropriately renumbered in order to identify the point to be unreliable (phase 1 and 2).

- The <u>efficiency</u> of the tests with respect ot small gross errors can reliably be predicted by theory. Unmodelled or uncompensated systmatic errors seem to be the main effect reducing the efficiency of the error detection by increasing the esitmate of the variance factor σ_o (phase 2).

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Table 2 Distributed Information on Simulated Blocks in Phase 1

Block M I/1

Model scale :	1 : 25 000
Day of flight :	10.4.1980
Day of measurements :	13.6. - 29.6.1980
Measurements :	image coordinates analytical relative orientation corrected for earth curvature
Quality of film :	low contrast
Quality of control points :	0.30 m planimetry 0.50 m height

Block M II/1

Model scale :	1 : 7000
Day of flight :	15.4.1980
Day of measurements :	1.6. - 10.6.1980
Measurements :	image coordinates analytical relative orientation corrected for earth curvature
Quality of film :	normal
Quality of control points :	0.2 m planimetry 0.2 m height

Block B I/1

Photo scale :	1 : 14 000
Day of flight :	22.4.1980 cloudy
Day of measurement :	1.6. - 15.6.1980 Strip I (5 - 17) Strip III, IV (31 - 56) 1.6. - 8.6.1980 Strip II (18 - 30)
Measurements :	reduced image coordinates, μm
Camera : RMK 15/23	c = 153.22 mm
Quality of film	normal
Quality of control points :	0,05 m planimetry 0,10 m height

Table 2 cont.

Block B II/2

Photo scale :	1 : 5000
Day of flight :	21.6.1979 strips I and II picture No. 5 - 30 RMK 15/23 No. 321 602 weather: dizzy
	23.6.1979 strips III and IV picture No. 31 - 56 RMK 15/23 No. 321 754 weather: bright
Day of measurements :	2.9. - 27.9. (picture No. 1-21, 27-36)
	5.9. - 16.9. (picture No.22-26)
	3.9. - 10.9. (picture No.37-56)
Measurements :	reduced image coordinates, µm
Cameras : No. 321 602	c̄ = 153.21 mm
No. 321 754	c = 153.24 mm
Quality of images :	good
Quality of control points :	0.01 m planimetry and height

Table 3 Distributed Information on Simulated Blocks in Phase 2

Block	M I /2	M II/2	B I /2	B II/2
Scale	1:20 000	1:8 000	1:15 000	1:3 000
Day of flight	2.4.83	11.3.75	2.5.65	3.5.65
Quality of film	low contrast	normal	good	excellent
Quality of control	σ_{XY} = 20 cm	5 cm	5 cm	1.5 cm
	σ_Z = 40 cm	12 cm	1 cm	5 cm

Measurements:

image coordinates in µm, c=153.24 mm
for model blocks: analytical relative orientation, model coordinates in µm

corrected for earth curvature and refraction

Table 4 Image Deformation in µm of Bundle Block BII/1, Strips 1 and 2

No.	x	y	Ebner dx	Ebner dy	Brown dx	Brown dy	total dx	total dy
1	-90000.00	90000.00	2.00	-4.79	-2.77	2.77	-0.77	-2.02
2	-45000.00	90000.00	0.37	-7.16	0.56	-1.12	+0.93	-8.28
3	0.00	90000.00	0.88	-6.39	0.00	-1.75	0.88	-8.64
4	45000.00	90000.00	3.55	-3.98	-0.56	-1.12	2.99	-5.10
5	90000.00	90000.00	8.37	1.56	2.77	2.77	11.14	4.33
6	-90000.00	45000.00	-2.16	-2.88	-2.67	1.33	-4.83	-1.55
7	-45000.00	45000.00	-1.72	-5.31	-0.06	0.06	-1.78	-5.25
8	0.00	45000.00	-0.57	-5.44	0.00	-0.09	-0.57	-5.53
9	45000.00	45000.00	1.30	-3.26	0.06	0.06	1.36	-3.20
10	90000.00	45000.00	3.88	1.22	2.67	1.33	6.55	2.55
11	-90000.00	0.00	-5.03	-1.35	-2.44	0.00	-7.47	-1.35
12	-45000.00	0.00	-3.14	-3.42	-0.11	0.00	-3.25	-3.42
13	0.00	0.00	-1.46	-3.49	0.00	0.00	-1.46	-3.49
14	45000.00	0.00	0.00	-1.58	0.11	0.00	0.11	-1.48
15	90000.00	0.00	1.25	2.33	2.44	0.00	3.69	2.33
16	-90000.00	-45000.00	-6.61	-0.22	-2.67	-1.33	-9.28	-1.55
17	-45000.00	-45000.00	-3.39	-1.48	-0.06	-0.06	-3.95	-1.54
18	0.00	-45000.00	-1.80	-1.05	0.00	0.09	-1.80	-0.96
19	45000.00	-45000.00	-0.35	1.07	0.06	-0.06	-0.29	-1.01
20	90000.00	-45000.00	0.47	4.87	2.67	-1.33	3.14	3.54
21	-90000.00	-90000.00	-6.89	0.53	-2.77	-2.77	-9.66	-2.24
22	-45000.00	-90000.00	-3.97	0.51	0.56	1.12	-3.41	1.63
23	0.00	-90000.00	-1.59	1.89	0.00	1.75	-1.59	3.64
24	45000.00	-90000.00	0.25	4.67	-0.56	1.12	-0.31	5.79
25	90000.00	-90000.00	1.54	8.85	2.77	-2.77	4.31	6.08

Table 5 Mean value and standard deviation of additional parameters in bundle blocks BI/2 and BII/2

Parameter	Block BI/2		Block BII/2	
	mean	sigma	mean	sigma
1	5.2	1.4	-0.5	0.7 µm
2	2.2	1.0	2.3	1.0
3	0.0	0.8	-1.7	0.7
4	1.7	0.9	0.5	1.1
5	-1.6	1.8	4.0	1.6
6	-5.3	1.1	0.3	2.0
7	0.6	2.3	14.5	2.1
8	-12.5	1.7	-1.7	2.2
9	1.8	1.3	1.8	1.5
10	3.2	1.1	1.1	1.5
11	-0.3	1.9	6.3	2.3
12	-3.2	1.9	-3.5	2.7

(cf. Schroth, 1982)

TABLE 6 GENERATED MODEL BLOCKS

		M I/1	M II/1	MI/2	M II/2
scale		1:25 000	1:7 000	1:20 000	1:8 000
system. errors		const.	const.	no	const.
model	$\sigma_{x,y}$ (μm)	10	5	8	4
	σ_z (μm)	15	8	12	7
projection centres	$\sigma_{x,y}$ (μm)	30	15	24	12
	σ_z (μm)	10	5	8	4
control points	$\sigma_{x,y}$ (m)	0.50	0.10	0.20	0.05
	σ_z (m)	0.10	0.20	0.40	0.12
n[1)]		1403	2844	1421	2844
u		901	1641	909	1641
r		502	1203	512	1203
r/n		0.36	0.42	0.36	0.42
no. of units		47	48	48	48
no. of gross errors		28	24	34	36
% of wrong points		2,3%	1,5%	2,8%	2,3%

1)

n= no. of observations

u= no. of unknowns

r= redundancy

TABLE 7 GENERATED BUNDLE BLOCKS

		B I/1	B II/1	B I/2	B II/2
scale		1: 14 000	1: 5 000	1 : 15 000	1 : 3 000
system. errors		const.	2 groups z-scale of CP	variable	variable
image σ_{xy} (μm)		5	3.0[2] 4.5[3]	4	2
control points	σ_{xy} (m)	0.06	0.02	0.05	0.015
	σ_z (m)	0.10	0.01	0.01	0.05
n[1]		1227	2739	1227	2739
u		887	1608	887	1608
r		340	1131	340	1131
r/n		0.28	0.41	0.28	0.41
no. of units		52	52	52	52
no. of gross errors		22	21	34	35
% of wrong points		2.8 %	1.5 %	4.3 %	2.5 %

1)
n= no. of oberservations
u= no. of unknowns
r= redundancy

2)
strips 1 and 2
3)
strips 3 and 4

Table 8 Gross Errors inserted into Model Block MI/1 (cf. Fig. 1)

large gross errors

1. model 454-450 point no. 161 ∇x = - 10 000 µm
   ∇y = + 12 000 µm
2. model 352-349 point no. 311 ∇x = - 10 000 µm
   ∇y = - 100 000 µm
3. control point no. 407 ↔ 443
4. horizontal control point no. 407 ∇x = - 72 000 m
5. horizontal control point no. 110 ∇y = - 10 000 m

medium-sized gross errors

6. model 577-573 point no. 113 ↔ 512
7. vertical control point no. 134 ∇z = - 100 m
8. models 555-552
   552-548 point no. 245 & , 248 → 245
9. models 367-363
   363-359 point no. 320 & , 53 → 320
10. model 461-465 point no. 95 & , 98 → 95
11. model 443-447 point no. 227 ∇x = - 70 000
    ∇y = - 46 000
12. projection centre no. 447 000 → 342 000
13. vertical control point no. 107 ∇z = 100 m
14. model 192-188 point no. 125 ↔ 146

small gross errors

15. vertical control point no. 23 ↔ 62
16. model 577-573 point no. 509 ∇x = + 200 µm
17. vertical control point no. 197 ∇z = - 30 µm
18. horizontal control point no. 443 ∇y = 18 m
19. model 469-465 point no. 68 ∇x = + 200 µm
    ∇y = - 200 µm
20. model 447-443 point no. 203 ∇x = + 150 µm
    ∇y = + 150 µm
21. vertical control point no. 338 ∇z = + 54 m
22. horizontal control point no. 32 ∇x = + 6 m
23. model 359-356 point no. 506 ∇x = + 60 µm
24. model 356-352 point no. 104 ∇x = - 150 µm
    ∇y = + 150 µm
25. model 349-346 point no. 146 ∇x = + 100 µm
    ∇y = + 100 µm
26. model 338-334 point no. 233 ∇x = - 300 µm
27. model 330-327 point no. 257 ∇x = - 50 µm
    ∇y = + 50 µm
28. model 172-169 point no. 239 ∇x = - 600 µm

Table 9 Gross Errors inserted into Model Block MII/1 (cf. Fig. 2)

large gross errors

1.	control point no.	74 ↔ 974	
		77 ↔ 977	
2.	horizontal control point no.	74	
		77	∇x = 10 000 m
3.	horizontal control point no.	383	∇x = 3 000 m
			∇y = 20 000 m
4.	vertical control point no.	170	
		173	∇z = 100 m
5.	model 569-566 point no.	260	
		263	∇x = - 100 000 µm
			∇y = + 100 000 µm
6.	model 447-463 point no.	401	∇x = 89 000 µm

medium-sized gross errors

7.	horizontal control point no.	32	
		35	∇x = - 20 µm
			∇y = - 90 m
8.	model 573-569 point no.	215	∇x = + 9 000 µm
9.	projection center	562 000 ↔ 559 000	
10.	model 555-559 point no.	434 → 443	
		431 → 434	
	555-552 point no.	431 → 434	
11.	no error		
12.	model 352-356 point no.	992 ↔ 995	
		1040 ↔ 1043	
		1091 ↔ 1094	
13.	model 352-356 point no.	233	∇x = 900 µm
14.	model 342-346		
	346-349 point no.	866 &, 329 → 866	
		764 & , 332 → 764	
		953 &	
15.	vertical control point no.	329 ↔ 455	
		332 ↔ 458	
16.	horizontal control point no.	425 ↔ 428	
17.	horizontal control point no.	206	
		209	∇x = + 10 m
			∇y = - 10 m

small gross errors

18.	model 584-581 point no.	128	
		131	∇z = + 200 µm
19.	model 473-469 point no.	98	∇y = - 70 µm
20.	model 469-465 point no.	149	∇x = + 120 µm
21.	vertical control point no.	446	∇z = 20 m
22.	model 330-327 point no.	692	∇y = - 100 µm
23.	projection centre no.	334 000	∇x = - 300 µm
24.	model 195-192 point no.	236	∇x = - 100 µm
			∇y = - 100 µm

Fig. 10 Gross Errors inserted into Bundle Block BI/1 (cf. Fig. 3)

large gross errors

1.	image 49	point no.	60 → 156	
2.	image 21	point no.	77 → 114 78 → 142	
3.	horizontal control	point no.	73	∇y = - 1000 m
4.	control point (x, y, z)		10 ↔ 13	

medium-sized gross errors

5.	horizontal control	point no.	6	∇x = + 10 m ∇y = - 63 m
6.	vertical control	point no.	113	∇z = - 20 m
7.	image 32	point no.	84 &,	132 → 84
8.	image 23	point no.	56	∇x = + 270 μm
9.	horizontal control	point no.	44	∇x = + 20 m ∇y = - 10 m
10.	image 7	point no.	87 &,	144 → 87

small gross errors

11.	image 54	point no.	14	∇x = - 70 μm ∇y = + 50 μm
12.	image 51	point no.	46	∇x = - 60 μm ∇y = - 60 μm
13.	vertical control	point no.	8	∇z = - 2.50 m
14.	image 53	points no.	29 and 30	∇x = 60 μm ∇y = 80 m
15.	image 40	point no.	171	∇y = - 120 μm
16.	image 41	point no.	17	∇y = + 120 μm
17.	horizontal control	point no.	136	∇x = - 0.50 m ∇y = - 0,60 m
18.	image 14	point no.	35	∇x = - 180 m ∇y = + 210 m
19.	image 23	point no.	71	∇x = + 200 m ∇y = - 120 m
20.	image 6	point no.	97	∇x = + 200 m ∇y = - 120 m
21.	vertical control	point no.	38	∇z = 98.5 m

Fig. 11 Gross Errors inserted into Bundle Block BII/1 (cf. Fig. 4)

large gross errors

1.	control points	no.	71 ↔ 128 72 ↔ 129	
2.	image 25	point no.	66 → 86 65 → 85	
3.	horizontal control	point no.	83	∇y = 10 000 m

medium-sized gross errors

4.	control points	no.	382 ↔ 326	
5.	horizontal control	point no.	325	∇x = + 360 m
6.	image 25	point no.	107	∇x = + 360 μm
7.	image 32	point no.	292 &, 225 → 292 321 &, 226 → 321	
8.	image 24	point no.	240 ↔ 255 275 ↔ 289 306 ↔ 318	
9.	vertical control	point no.	25	∇z = + 10 m
10.	image 7	point no.	300 &, 340 → 300	

small gross errors

11.	image 54	point no.	29	∇y = + 20 μm
12.	image 50	point no.	117	∇x = 60 μm
13.	control point	no.	19	∇x = 0.20 m ∇y = - 0.10 m ∇z = + 0.15 m
14.	images 27, 28	point no.	49	∇x = + 60 μm ∇y = - 120 μm
	29	point no.	49	∇x = + 60 μm ∇y = + 120 μm
15.	images 34, 35, 36	point no.	219, 220, 221	∇x = + 150 μm ∇y = + 30 μm
15.	image 22	point no.	122	∇x = - 120 μm ∇y = 20 μm
17.	images 20, 21, 22	point no.	152 ↔ 153	
18.	vertical control	point no.	189	∇z = - 0.20 m
19.	image 15	point no.	67	∇x = - 130 μm
20.	image 9	point no.	154	∇y = + 50 μm
21.	horizontal control	point no.	142	∇x = 0.16 m ∇y = - 0.12 m ∇z = + 0.08 m
22.	vertical control	point no.	71	∇z = 54 m

Table 12 Gross Errors inserted into Model Block MI/2 (cf. Fig. 5)

Error No.	Type	Point No.	Model No.	Coord.	Size
1	ex	65 - 458	584/581	xyz	-
2	ex	272 - 485	330/327	z	-
3	ex	116 - 482	573/569	xyz	-
4	gr	380/224	443/439	z	+ 100 µm
5	gr	329/212	342/338	x	- 80
6	0.7	176	184/180	y	+ 60
7	.	113	577/573	z	- 90
8	.	188	346/342	y	- 40
9	.	206	447/443	x	+ 45
10	1.0	197	562/559	x	+ 90
11	.	215	180/176	z	- 90
12	.	290	165/161	z	+ 130
13	.	59	203/199	y	- 95
14	.	71	469/465	x	- 50
15	.	221	555/552	z	+ 90
16	.	158	569/566	x	- 60
17	1.3	92	469/465	z	- 110
18	.	317	477/473	y	+ 80
19	.	143	461/457	y	- 75
20	.	146	192/188	x	+ 90
21	.	515	165/161	z	+ 160
22	.	101	356/352	y	+ 75
23	1.6	29	367/363	x	+ 140
24	.	170	184/180	z	+ 150
25	.	128	192/188	y	- 90
26	.	56	363/359	x	+ 90
27	.	494	548/544	z	- 250
28	20.	350	435/432	x	+ 1000
29	50.	311	349/346	y	+ 5000
30	150.	182	454/450	x	+ 200000
31	2. HO	407		x	+ 2.80 m
32	2. VE	107		z	+ 6.50 m
33	4. HO	194		y	+ 5.00 m
34	4. VE	62		z	- 12.00 m

Fig. 13 Gross Errors inserted into Model Block MII/2 (cf. Fig. 6)

Error No.	Type	Point No.	Model No.	Coord.	Size
1	ex	632-896-797	342/338	xyz	-
2	ex D	710/908-200/203	199/195	xyz	-
3	ex	176-179	465/461	xyz	-
4	0.7	395	559/555	y	- 20 µm
5	.	299	566/562	z	+ 40
6	.	683	552/548	y	+ 25
7	. D	341/344	184/180	x	- 40
8	.	116/119	206/203	x	+ 40
9	.	197/194	199/195	z	- 45
10	1.0	605	203/199	z	+ 50
11	.	179	465/461	y	+ 25
12	.	374	346/342	x	- 22
13	. PC	169	169/165	x	-170
14	. D	521/524	552/548	z	- 60
15	. D	266/269	461/457	x	+ 30
16	1.3	854	435/432	z	- 60
17	.	56	477/473	y	+ 40
18	.	227	461/457	x	- 30
19	.	452	334/330	x	+ 30
20	. D	32/35	588/584	y	- 75
21	. D	506/503	334/330	x	- 35
22	1.6	362	450/447	z	- 70
23	.	275	457/454	x	+ 35
24	.	968	352/349	y	+ 40
25	. PC	359	359/356	x	-230
26	. D	191/188	359/356	x	- 40
27	.	263/260	573/569	z	+ 70
28	2.0	314	454/450	y	- 50
29	. PC	435	435/432	x	-250
30	. T	1154/125/122	581/577	z	+ 120
31	6.0 D	158/161	199/195	z	-250
32	50.0 D	80/83	584/581	x	+ 1500
33	2.0 HO	977/974		y	+ 2.0 m
34	2.0 VE	458/455		z	- 1.4
35	4.0 HO	425/428		x	+ 2.0
36	4.0 VE	1166		z	+ 3.0

Fig. 14 Gross Errors inserted into Bundle Block BI/1 (cf. Fig. 7)

Error No.	Type	Point No.	Image No.	Coord.	Size
1	ex	172/93	6	-	-
2	ex	29/30	53	-	-
3	gr	31/32	41(37)	x	÷ 50 µm
4	gr	138/152	34(30)	x	-100
5	2.0	56	24	x	- 40
6	.	90	18	x	+ 70
7	1.0	47	38	y	+ 20
8	.	63	23	x	- 35
9	.	53	50	x	+ 20
10	.	171	52	x	+ 20
11	.	13	17	y	+ 35
12	.	8	55	x	+ 30
13	.	115	33	y	- 20
14	1.3	111	26	y	- 24
15	.	27	16	x	- 40
16	.	10	29	x	+ 28
17	.	81	45	x	- 70
18	.	106	42	y	+ 30
19	1.6	61	35	y	- 28
20	.	98	5	y	+ 40
21	.	46	52	x	- 52
22	.	37	13	x	- 60
23	2.0	107	28	x	+ 60
24	.	149	5	y	÷ 90
25	.	15	55	y	- 45
26	.	83	33	x	- 60
27	2.	VE 38		z	+ 1.8 m
28	2.	HO 44		x	- 1.2
29	4.	VE 147		z	- 3.0
30	4.	HO 73		y	- 1.5
31	6.	35	15	x	+ 150 µm
32	18.	142	47	y	+ 500
33	50.	77	20	x	- 1000
34	150.	162	6	y	- 4000

Fig. 15 Gross Errors inserted into Bundle Block BII/2 (cf. Fig. 8)

Error No.	Type	Point No.	Image	Coord.	Size
1	ex	308 - 242	37	-	-
2	ex	359 - 342	14	-	-
3	gr	245/281/311	47	y	+ 15 μm
4	gr	80/79	12	x	+ 20
5	gr	116/117	50	y	- 20
6	gr	182/183/393	7	x	+ 45
7	0.7	391	51	x	+ 10
8	.	120	37	x	- 10
9	.	367	45	x	- 11
10	.	230	32	x	- 8
11	1.0	186	44	x	+ 13
12	.	289	24	y	- 12
13	.	130	48	y	+ 10
14	.	250	32	y	- 14
15	1.3	159	46	y	- 20
16	.	210	13	x	+ 30
17	.	63	27	y	- 18
18	.	194	5	y	+ 25
19	.	69	13	y	- 20
20	1.6	170	8	x	÷ 36
21	.	144	48	y	+ 24
22	.	111	10	y	+ 20
23	.	232	19	x	- 22
24	1.0 VE	12	-	z	+ 14 cm
25	1.5 VE	390	-	z	- 12
26	2.0 VE gr	25/26	-	z	- 30
27	1.5 VE	79	-	z	+ 12
28	1.0 HO	20	-	x	+ 8
29	2.0 HO	193	-	y	- 30
30	1.5 HO gr	71/72	-	xy	- 12
31	2. gr	39/40	15	xy	+ 40/- 30 μm
32	6. gr	137/136	21	x	- 120
33	18.	55	54	x	+ 400
34	50.	190	5/18	xy	+1000/+1000
35	150	220	34	y	+3000

Table 16 Performance Statistics for Model Block MI/1

	1	2	3	4	5	6	7	8	9	10	11	12
participant	K	L	B	E	O	M	G	P	Q	H	I	S
performance index I_p	6	7	11	12	13	14	15	16	18	20	25	33
missed errors n_m	3	5	8	10	11	8	12	9	12	7	7	13
del. correct observ. n_c	3	2	3	2	2	6	3	7	6	13	18	20
plot of residuals	-	-	P	-	-	P	P	P	-	P	P	P
data-snooping	D	D	-	-	-	-	-	-	-	-	-	-
runs	44	7	11	3	.	14	.	.	.	10	19	8
strategy index I_s	4	4	-	2	-	4	4	4	-	4	4	4
time for initial prep. $\|h\|$	4	.	1	9	.	5	.	.	.	.	.	20
time for run prep. $\|h\|$	62	.	.	7	.	40	.	40	.	.	.	20
$\hat{\mu}_{xy}$	.53	.75	1.5	.	1.7	.	.	2.8	1.5	.	.	.
$\hat{\mu}_z$	1.2	1.1	1.0	.	24.	.	.	52.	54.	.	.	.
max v_{xy}	2.2	3.0	4.9	.	4.9	.	.	18.0	4.7	.	.	.
max v_z	3.4	2.8	3.4	.	137.	.	.	125.	153.	.	.	.
N eliminated	1	1	16	.	15	.	.	-	18	.	.	.
N not listed	10	8	5	.	9	.	.	6	7	.	.	.

Table 17 Performance Statistics for Model Block MII/2

	1	2	3	4	5	6	7	8	9
participant	L	M	O	E	H/I	B	G	R	S
performance index I_p	1	4	5	6	7	7	7	12	24
missed errors n_m	1	4	5	6	2	5	6	2	9
del. correct observ. n_c	0	0	0	0	5	2	1	10	15
plot of residuals	-	P	P	-	P	P	P	P	P
data-snooping	D	-	-	-	-	-	-	-	-
runs	12	6	.	3	12	6	.	12	7
strategy index I_s	4	3	2	2	4	-	4	2	2
time for initial prep. $\|h\|$	.	.	.	18	.	-	.	3	15
time for run prep. $\|h\|$	.	11	40	10	.	.	.	7	10
$\hat{\mu}_{xy}$	.13	.	.13	.	.	.13	.	.20	.
$\hat{\mu}_z$	.14	.	.19	.	.	.16	.	.18	.
max v_{xy}	.34	.	.45	.	.	.55	.	.54	.
max v_z	.36	.	.53	.	.	1.0	.	.44	.
N eliminated	3	.	3	.	.	4	.	0	.
N not listed	(∞)	.	22	.	.	11	.	(∞)	.

Table 18 Performance Statistics for Bundle Blocks BI/1 and BII/2

	BI 1	2	3	4	5	6	BII: 1	2	3	4	5
participant	C	B	D	A	J	F	F	D	B	C	N
performance index I_p	5	7	7	7	8	33	5	7	8	11	11
missed errors n_m	5	5	5	6	2	6	4	1	2	6	6
del. correct observ. n_c	0	2	2	1	6	27	1	6	6	5	5
plot of residuals	-	P	-	P	-	-	-	-	P	-	-
data-snooping	D	-	-	-	D	-	-	-	-	D	-
groups of add. parameters	-	1	1	-	1	1	1	2	-	1	-
runs	8	19	3	10	6	11	4	3	18	8	11
strategy index I_s	3	5	2	5	4	3	4	2	5	3	7
time for initial prep. |h|	1	1/2	6	1	.	.	.	6	1/2	1	.
time for run prep. |h|	5	.	1	7	.	40	28	1	.	5	14
$\hat{\mu}_{xy}$	.36	.22	.21	.	.58	.	.05	.	.05	.12	.10
$\hat{\mu}_z$	.61	.53	.58	.	.24	.	.16	.	.17	.18	.15
max v_{xy}	1.3	.71	.73	.	1.9	.	1.9	.	.25	.75	1.1
max v_z	2.4	2.4	2.4	.	.8	.	.62	.	.48	.63	.55
N eliminated	1	0	1	.	19	.	0	.	0	0	0
N not listed	3	4	3	.	11	.	15	.	11	9	13

Table 19 Relative Efficiency of Error Detection Procedures in Phase 1

MI-1

weight	type	1	2	3	4	5	6	7	8	9	10	11	12
5	#	12	11			8	9	12	12	9	11	11	4
4	+	6	14	19	16	9	7	8	8	11	9	12	11
3	o							1	1				
0	−	10	3	9	12	11	11	7	7	8	8	4	13
−3	w						1					1	
	Σ	84	111	76	64	76	70	92	92	89	91	100	64
	∅	3.0	4.0	2.7	2.3	2.7	2.5	3.3	3.3	3.2	3.3	3.6	2.3
	E	59	<u>93</u>	49	34	49	41	69	69	65	68	<u>79</u>	34 %

min = 37 max = 114

MII-1

type	1	2	3	4	5	6	7	8	9	10
#	17	13	11	15	15	9	3	15	12	5
+	1	5	5	5	5	9	15	4	11	9
o		1	2	2	2	2	3			1
−	6	5	6	1	1	4	3	4	1	9
w				1	1			1		
Σ	89	85	75	92	92	87	75	88	104	61
∅	3.7	3.5	3.1	3.8	3.8	3.6	3.1	3.7	4.3	2.5
E	66	61	46	70	70	63	46	65	<u>87</u>	27 %

min = 42 max = 113

BI-1

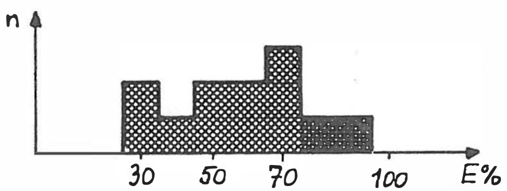
type	1	2	3	4	5	6
#	9	8	9	9	4	5
+	6	8	7	6	13	7
o				1	1	3
−	5	3	4	4	2	6
w	1	2	1	1		
Σ	66	66	70	69	78	62
∅	3.1	3.1	3.3	3.3	3.7	3.0
E	51	51	60	<u>58</u>	<u>78</u>	42 %

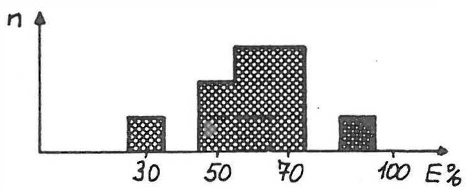
min = 43 max = 88

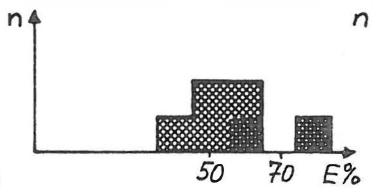
BII-1

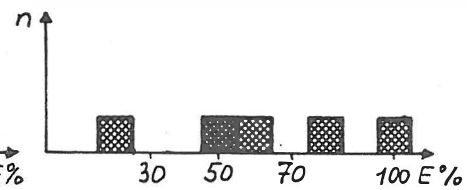
type	1	2	3	4	5
#	6	11	10	10	9
+	8	10	8	3	8
o	2		2	3	1
−	6	1	2	6	4
w					
Σ	68	95	88	71	80
∅	3.1	4.3	4.0	3.2	3.6
E	24	97	78	<u>52</u>	57 %

min = 59 max = 96









$\Sigma = \Sigma\, n_{type} * weight_{type}$; $\emptyset = \Sigma / \Sigma n_{type}$; min, max = Σmin(weight), Σmax(weight) reached ; $E[\%] = 100 \cdot \frac{\Sigma - min}{max - min}$

■ = <u>with data-snooping</u>

Table 20 Strategies for Adjustments with Independent Models, Sequence of Steps

	1	2	3	4	5	6	7	8	9	10
participant	E	G	H	K	L	M	O	P	R	S
strip adjustment	1				2	2	1	1		
- without CP			1	1	1	1				
strip connection			2	2	3			2		
subblocks		2								
- without CP		1								
block adjustment	2	3	3	4	4	3	2	3	1	1
- without CP				3						
plot of residuals		x	x			x		x	x	x
strategy index l_s	2	4	4	4	4	4	2	4	2	2

Table 21 Startegies for Adjustments with Bundles, Sequence of Steps

	1	2	3	4	5	6	7
participant	A	B	C	D	F	J	N
relative orient.	1	1		1	1	1	1
resection							3
scale transfer					2		
absolute orient.					3		
strip adjustment	2	2	1			2	
- without CP							2
strip connection	3	3	2			3	
subblocks							6
- without CP							4
subblock connect.							5
block adjustment	4	4	3	2[1)]	4	4	7
plot of residuals	x	x					
strategy index l_s	5	5	3	2	4	4	7

1) automatic procedure

Table 22 Reactions on Errors in Model Block MI/2

	ERROR NO.	TYPE	SIZE	PARTICIPANT 1[1]	2[2]	3	4	5
1	6	0.7	60 y	-	-	-	-	-
2	7	0.7	90 z	-	-	-	-	-
3	8	0.7	40 y	-	-	-	-	-
4	9	0.7	45 x	-	-	-	-	-
5	10	1.0	90 x	-	-	-	-	100 ●
6	11	1.0	90 z	130 +	+	110 +	100 0	100 ●
7	12	1.0	130 z	-	-	-	-	-
8	13	1.0	95 y	-	-	-	-	80 +
9	14	1.0	50 x	-	-	-	50 0	50 +
10	15	1.0	90 z	-	-	82 +	100 +	80 +
11	16	1.0	60 x	-	-	-	-	-
12	17	1.3	110 z	130 +	+	134 +	150 0	140 +
13	18	1.3	80 y	90 0	-	77 +	80 #	80 +
14	19	1.3	75 y	70 0	-	82 +	75 +	80 +
15	20	1.3	90 x	-	-	112 +	75 +	80 +
16	21	1.3	160 z	160 +	+	164 +	160 #	170 +
17	22	1.3	75 y	-	-	-	50 0	-
18	23	1.6	140 x	-	-	-	-	-
19	24	1.6	150 z	160 0	0	150 +	100 +	160 +
20	25	1.6	90 y	90 +	-	112 +	100 0	100 ●
21	26	1.6	90 x	75 +	-	-	50 0	80 +
22	27	1.6	250 z	240 +	+	262 +	250 Ø	230 +
23	31	2 HO	2.8 X	-	-	-	3. +	-
24	32	2 VE	6.5 Z	-	-	5. ●	10. +	7. +
25	33	4 HO	5.0 Y	-	-	-	5. +	6. +
26	34	4 VE	12.0 Z	-	-	10. ●	10. ●	10. ●
27	28	20	1000 x	1000 +	+	1000 +	1000 +	1000 #
28	29	50	5000 y	5000 +	+	5000 +	5000 +	5000 #
29	30	150	20000 z	20000 +	?	20000 +	20000 #	20000 #
30	1	ex	-	0	#	#	#	#
31	2	ex	-	0	-	+	#	#
32	3	ex	-	0	0	#	#	#
33	4	gr	100 z	100 ■	-	-	x	x
34	5	gr	80 x	-	-	-	-	-
no. of deleted correct observ. n_c				0	3	4	5	1
no. of missed gross errors n_m				18	25	16	10	10
Performance index $I_p = n_c + n_m$				18	28	20	15	11

[1]only check of model connections [2]only strip adjustment

Table 23 Reactions on Errors in Model Block MII/2

	ERROR NO.	TYPE	SIZE	PARTICIPANT 1[1]	2[2]	3	4	5
1	4	0.7	20 y	-	-	-	-	-
2.	5	0.7	40 z	-	-	-	-	-
3	6	0.7	25 y	-	-	-	-	-
4	7	0.7 D	40 x	-	-	-	-	-
5	8	0.7 D	40 x	-	-	-	-	-
6	9	0.7 D	45 z	55 0	-	-	+	-
7	10	1.0	50 z	70 +	+	-	+	-
8	11	1.0	25 y	-	-	-	-	-
9	12	1.0	22 x	-	-	-	-	-
10	13	1.0 PC	170 x	-	-	-	-	170 +
11	14	1.0 D	60 z	-	-	-	-	-
12	15	1.0 D	30 x	-	+	-	-	-
13	16	1.3	60 z	-	-	-	-	-
14	17	1.3	40 y	-	-	+	45 ?	-
15	18	1.3	30 x	-	-	-	-	-
16	19	1.3	30 x	-	-	-	-	-
17	20	1.3 D	75 y	-	-	●	-	-
18	21	1.3 D	35 x	-	-	-	+	-
19	22	1.6	70 z	80 0	-	-	0	-
20	23	1.6	35 x	-	-	-	0	40 +
21	24	1.6	40 y	55 0	-	+	35 ?	50 +
22	25	1.6 PC	230 x	-	-	+	-	210 +
23	26	1.6 D	40 x	-	-	-	-	-
24	27	1.6 D	70 z	70 0	-	-	0	-
25	28	2	50 y	+	-	-	0	60 +
26	29	2 PC	250 x	-	-	-	-	-
27	30	2 T	120 z	80 0	-	-	-	-
28	33	2 HO	2.0 y	-	-	-	0	-
29	34	2 VE	1.4 z	-	-	-	+	1.4 +
30	35	4 HO	2.0 x	-	-	0.6 0	+	0.6 +
31	36	4 VE	3.0 z	-	-	●	+	3.6 +
32	31	6 D	250 z	135 0	0	250 +	+	260 +
33	32	50 D	1500 x	-	-	+	+	1500 +
34	1	ex		0	0	#	#	#
35	2	ex		#	#	#	#	#
36	3	ex		0	0	#	?	#
no. of deleted correct observ. n_c				2	0	8	2	1
no. of missed gross errors n_m				25	30	25	18	23
Performance index $I_p = n_c + n_m$				27	30	33	20	24

[1] only check of model connections [2] only strip adjustment

Table 24 Reactions on Errors in Bundle Block BI/2

	ERROR NO.	TYPE	SIZE	PARTICIPANT 1	2	3	4
1	7	1.0	20 y	50 +	42 +	40 +	40 +
2	8	1.0	35 x	-	-	-	40 0
3	9	1.0	20 x	-	-	-	-
4	10	1.0	20 x	?	-	-	-
5	11	1.0	35 y	-	-	-	-
6	12	1.0	30 x	-	-	-	-
7	13	1.0	20 y	-	-	-	-
8	14	1.3	24 y	80 +	-	-	40 +
9	15	1.3	40 x	-	-	-	-
10	16	1.3	28 x	-	-	-	-
11	17	1.3	70 x	-	-	-	-
12	18	1.3	30 y	65 +	-	-	30 +
13	19	1.6	28 y	50 +	-	-	50 +
14	20	1.6	40 y	-	-	-	30 0
15	21	1.6	52 x	130 +!	-	75 0[1]	40 +!
16	22	1.6	60 x	-	-	-	(70)0
17	23	2.0	60 x	50 +	39 +	80 0[1]	60 0
18	24	2.0	90 y	80 +	90 +	100 +	100 +
19	25	2.0	45 y	80 +	-	-	60 +
20	26	2.0	60 x	50 +	58 +	50 +	60 +
21	5	2.0	40 x	50 +	45 +	(50)0[1]	60 0
22	6	2.0	70 x	50 +	-	75 0[1]	(80)0
23	27	2.0 VE	1.8 Z	4.0 ●	-	-	2.4 +
24	28	2.0 HO	1.2 X	.8 ●	-	-	-
25	29	4.0 VE	3.0 Z	-	3.0 #	2.0 +	3.0 +
26	30	4.0 HO	1.5 Y	1.0 ●	-	-	1.0 +
27	31	6	150 x	300 +	155 +	150 +	150 #
28	32	18	500 y	1000 +	488 +	500 +	500 #
29	33	50	1086 x	636 0	525 +	1000 0[1]	(1000)0
30	34	150	4000 y	4000 +	4000 #	4000 +	4000 #
31	1	ex	-	#	#	#	#
32	2	ex	-	#	#	#	#
33	3	gr	50 x	-	-	-	-
34	4	gr	100 x	65 x	50 x	100 x	(120)0
no. of deleted correct observ. n_c				7	0	3	6
no. of missed gross errors n_m				12	21	19	11
Performance index $I_p = n_c + n_m$				19	21	22	17

[1] being aware to possibly reject an error free observation

Table 25 Reactions on Errors in Bundle Block BII/2

	ERROR NO.	TYPE	SIZE	PARTICIPANT 1	2	3	4
1	7	.7	10 x	45 0	-	-	-
2	8	.7	10 x	-	-	-	-
3	9	.7	11 x	-	-	-	-
4	10	.7	8 x	-	-	-	-
5	11	1.0	13 x	-	-	-	-
6	12	1.0	12 y	-	-	-	-
7	13	1.0	10 y	70 +	-	-	-
8	14	1.0	14 y	-	-	-	-
9	15	1.3	20 y	20 +	-	20 +	20 +
10	16	1.3	30 x	+	22 +	35 0[1]	(40)0
11	17	1.3	18 y	30 +	22 +	-	20 +
12	18	1.3	25 y	-	25 0	20 +	-
13	19	1.3	20 y	40 +	33 +	30 +	30 +
14	20	1.6	36 x	(50)0	-	45 0[1]	(40)0
15	21	1.6	24 y	-	35 +	35 +	30 +
16	22	1.6	20 y	50 +	21 +	21 +	20 +
17	23	1.6	22 x	20 +	15 +	20 +	30 +
18	24	1.0 VE	.14 Z	●	0	-	-
19	25	1.5 VE	.12 Z	●	.26 +	.25 +	.23 +
20	26	2.0 VE gr	.30 Z	-	-	-	-
21	27	1.5 VE	.12 Z	-	-	-	-
22	28	1.0 HO	.08 X	●	.12 +	.11 +	.12 +
23	29	2.0 HO	.30 Y	.30 #	.27 +	.25 +	.28 +
24	30	1.5 HO gr	.12 X/Y	-	-	-	-
25	31	2.	50 x/y	-	34 0!	-	-
26	32	6.	120 x	100 +	(118)+	100 0[1]!	100 0
27	33	18.	400 x	400 +	(402)+	400 0[1]	400 #
28	34	50.	1414 x/y	? +	1400 +	? 0	1414 #
29	35	150.	3000 y	3000 #	3000 +	3000 +	3000 #
30	1	ex	-	#	#	+	#
31	2	ex	-	#	#	#	#
32	3	gr	15 y	-	-	18 +	-
33	4	gr	20 x	-	-	-	-
34	5	gr	20 y	-	-	-	-
35	6	gr	45 x	-	-	-	-
no. of deleted correct observations n_c				23	2	0	1
no. of missed gross errors n_m				16	17	17	18
Performance index $I_p = n_c + n_m$				39	19	17	19

[1] being aware of possibly rejecting a correct observation

Table 26 Empirical Efficiency and Features of Error Detection Procedures Phase 2

a) Model Blocks

	MI/2								MII/2							
	Y	Y	W	U	T				Y	Y	W	U	T			
SIZE	1	2	3	4	5	MIN	ϕ	MAX	1	2	3	4	5	MIN	ϕ	MAX
0.7	0	0	0	0	0	0	0	0	.17	0	0	.17	0	0	.06	.17
1.0	.14	.14	.29	.43	.71	.14	.34	.71	.17	.33	0	.17	.17	0	.17	.33
1.3	.67	.33	.83	1.0	.83	.33	.73	1.0	0	0	.33	.33	0	0	.13	.33
1.6	.80	.40	.60	.80	.80	.40	.68	.80	.50	0	.33	.67	.50	0	.40	.67
2.0	–	–	–	–	–	–	–	–	.67	0	0	.33	.33	0	.27	.67
D	+	+	+	–	+				+	+	+	–	+			
S	–	–	–	–	–				–	–	–	–	–			
A	–	–	+	–	–				–	–	+	–	–			
n_c	0	3	4	5	1				2	0	8	2	1			
n_m	18	25	16	10	10				25	30	25	18	23			
I_p	18	28	20	15	11				27	30	33	20	24			

b) Bundle Blocks

	BI/2							BII/2						
	Z	X	V	U				Z	X	V	U			
SIZE	1	2	3	4	MIN	ϕ	MAX	1	2	3	4	MIN	ϕ	MAX
0.7	–	–	–	–	–	–	–	.25	0	0	0	0	.08	.25
1.0	.29	.14	.14	.29	.14	.21	.29	.25	0	0	0	0	.08	.25
1.3	.40	0	0	.40	0	.20	.40	.80	.80	.80	.80	.80	.80	.80
1.6	.50	0	.25	1.0	0	.44	1.0	.75	.75	1.0	1.0	.75	.88	1.0
2.0	1.0	.67	.83	1.0	.67	.87	1.0	–	–	–	–	–	–	–
D	+	–	+	–				+	–	+	–			
S	+	+	+	+				+	+	+	+			
A	–	+	–	–				–	+	–	–			
n_c	7	0	3	6				23	2	0	1			
n_m	12	21	19	11				16	17	17	18			
I_p	19	21	22	17				39	19	17	19			

D: data-snooping
S: self-calibration
A: automatic weight reduction

n_c: no. of deleted correct observations
n_m: no. of missed gross errors
I_p: no. of wrong decisions
Performance Index $I_p = n_c + n_m$

Table 27   Absolute Accuracy of Cleaned Bundle Blocks in Phase 2

	BLOCK BI/2				BLOCK BII/2			
	1/U	2/X	3/V	4/Z	1/V	2/U	3/Z	4/X
Data-Snooping	-	-	D	D	D	-	D	-
Points Not Listed	6	7	5	10	7	18	9	13
Points Compared	159	158	160	155	369	358	367	363
ε_{xy} max [m]	1.43	1.41	1.75	1.44	.14	.19	.17	.15
ε_z max [m]	2.71	2.61	2.62	3.04	.36	.40	.38	.29
μ_{xy} [m]	.27	.36	.39	.37	.038	.040	.045	.043
μ_z [m]	.44	.56	.64	1.22	.076	.072	.083	.108
ε_{xy} max / μ_{xy}	5.3	3.9	4.4	3.9	3.7	4.8	3.8	3.5
ε_z max / μ_z	6.2	4.7	4.1	2.5	4.7	5.6	4.6	2.7
$\hat{\mu}_{xy}$ [m]	-	.18	.13	.05	.012	-	.005	.025
$\hat{\mu}_z$ [m]	-	-	.28	.10	.027	-	.010	.060
$\hat{\mu}_{xy}$ / μ_{xy}	-	.50	.33	.14	.32	-	.11	.48
$\hat{\sigma}_o$ [μm]	5.7	7.9	6.5	3.5	3.3	3.5	2.7	3.8
$\hat{\sigma}_o$ / σ_o	1.4	2.0	1.6	0.9	1.6	1.7	1.3	1.9

Fig. 1 Gross Errors inserted into Model Block MI/1 (cf. Tab. 8)

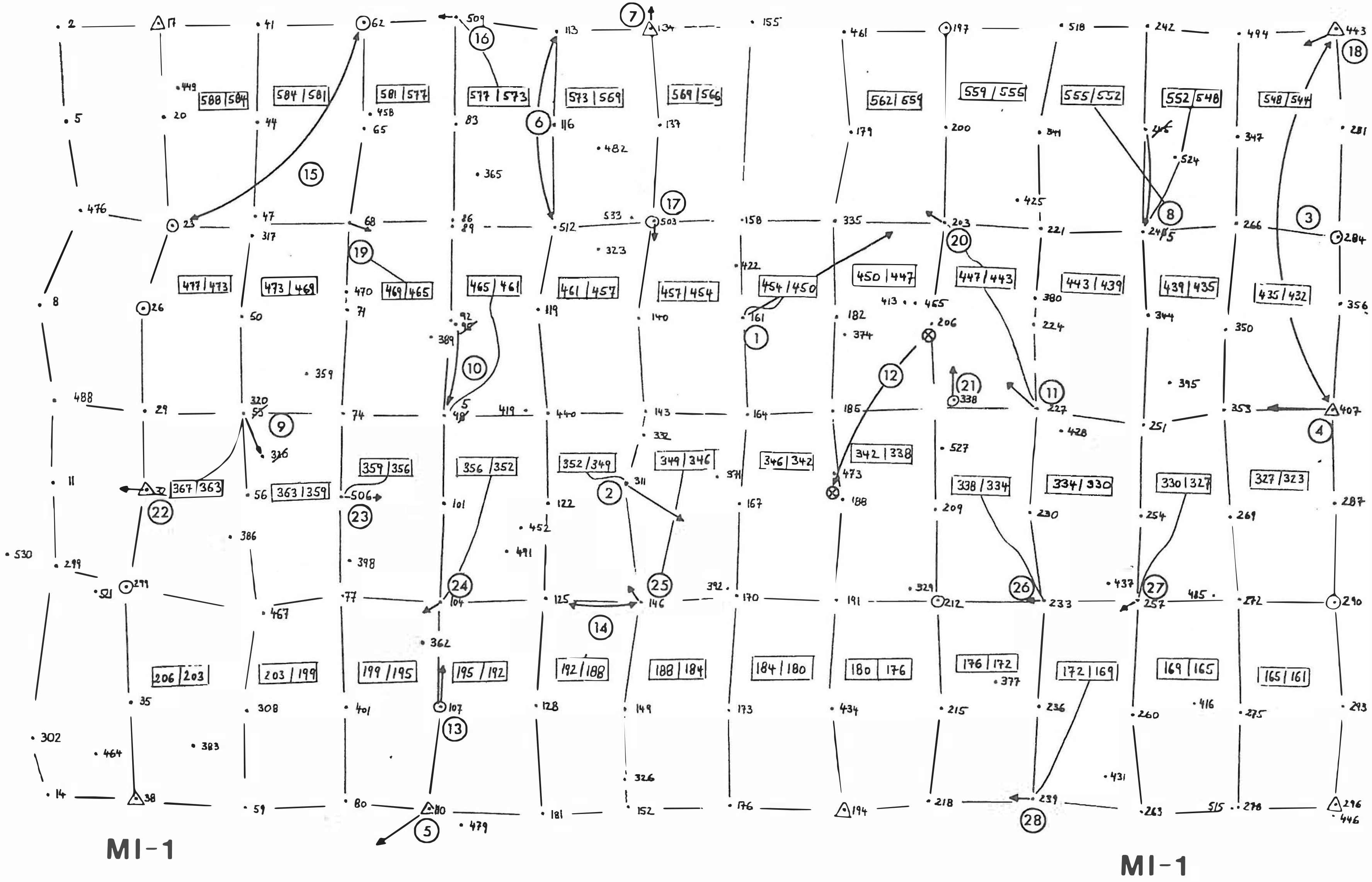
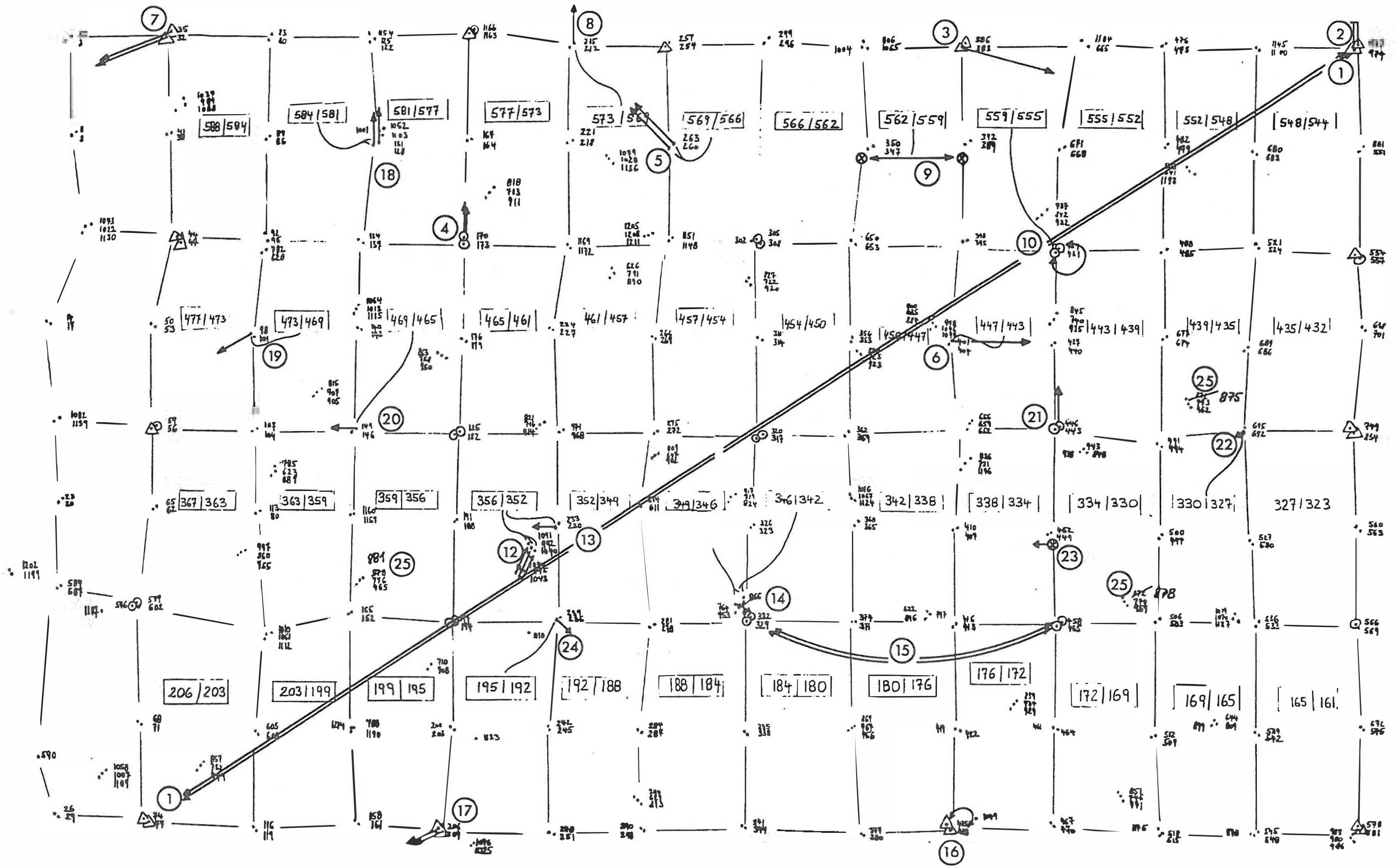


Fig. 2   Gross Errors inserted into Model Block MII/1 (cf. Tab. 9)



MII-1   MII-1

Fig. 3 Gross Errors inserted into Bundle Block BI/1 (cf. Tab. 10)

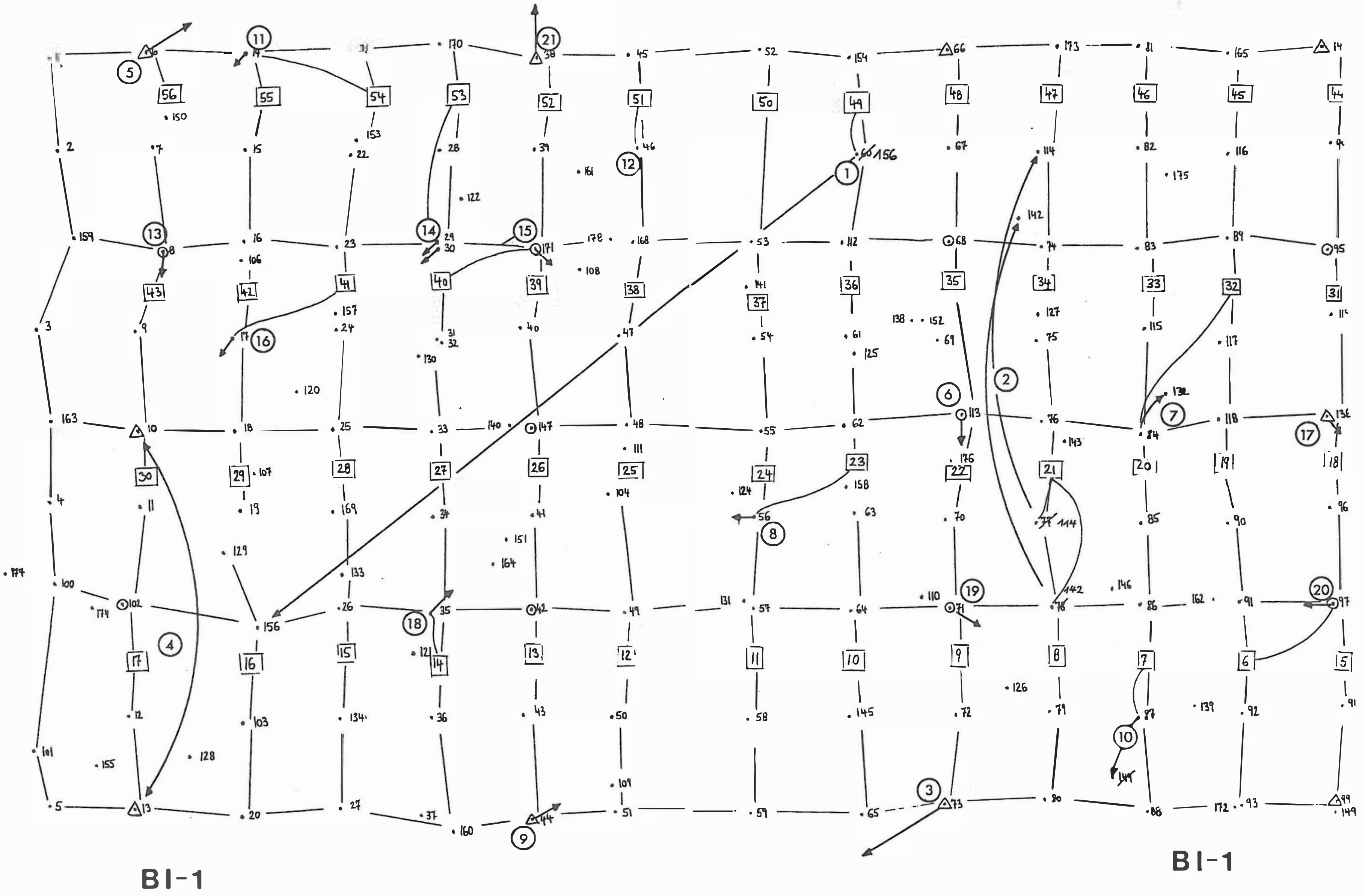
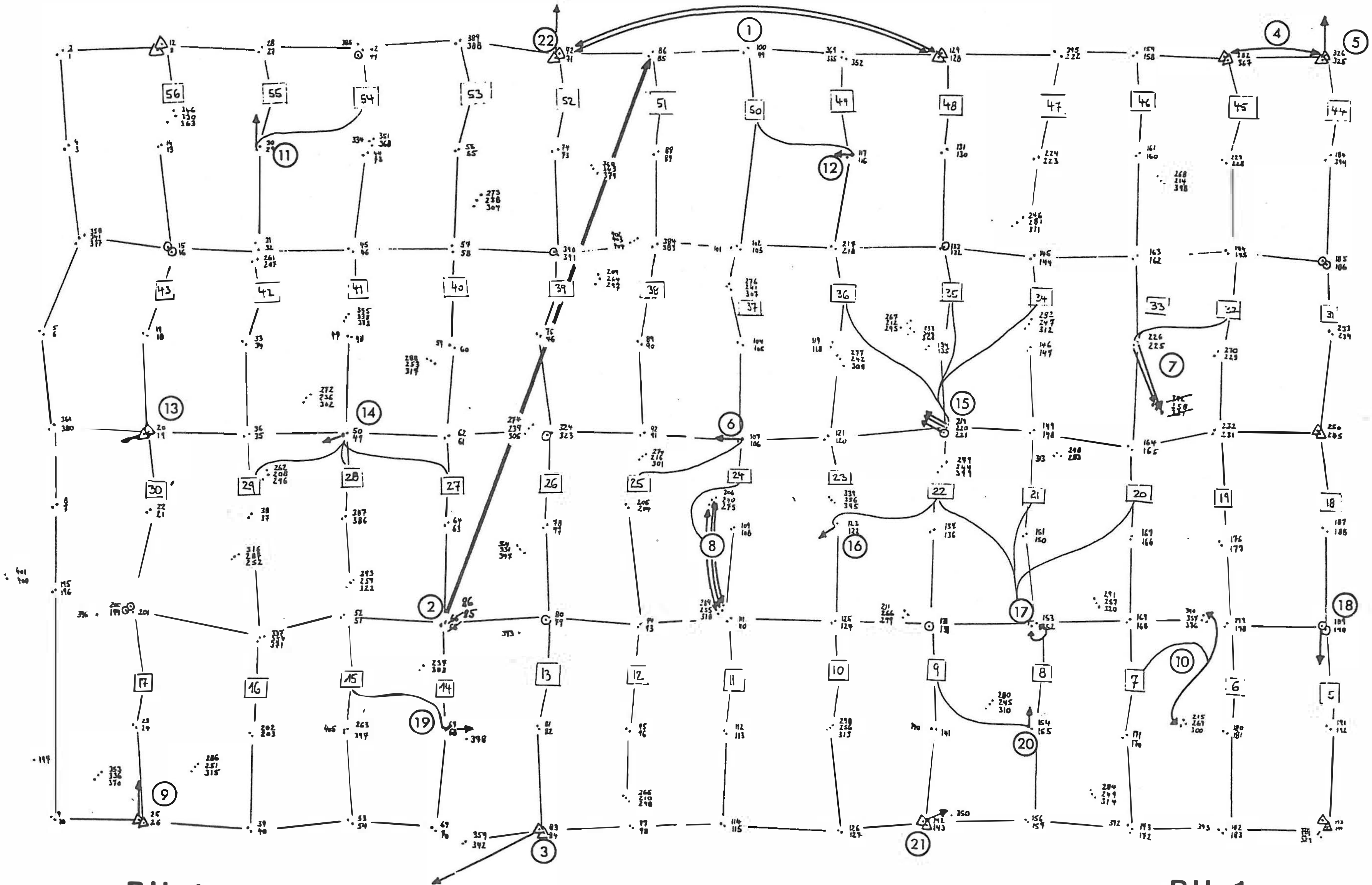


Fig. 4   Gross Errors inserted into Bundle Block BII/1 (cf. Tab. 11)



BII-1   **BII-1**

Fig. 5 Gross Errors inserted into Model Block MI/2 (cf. Tab. 12)

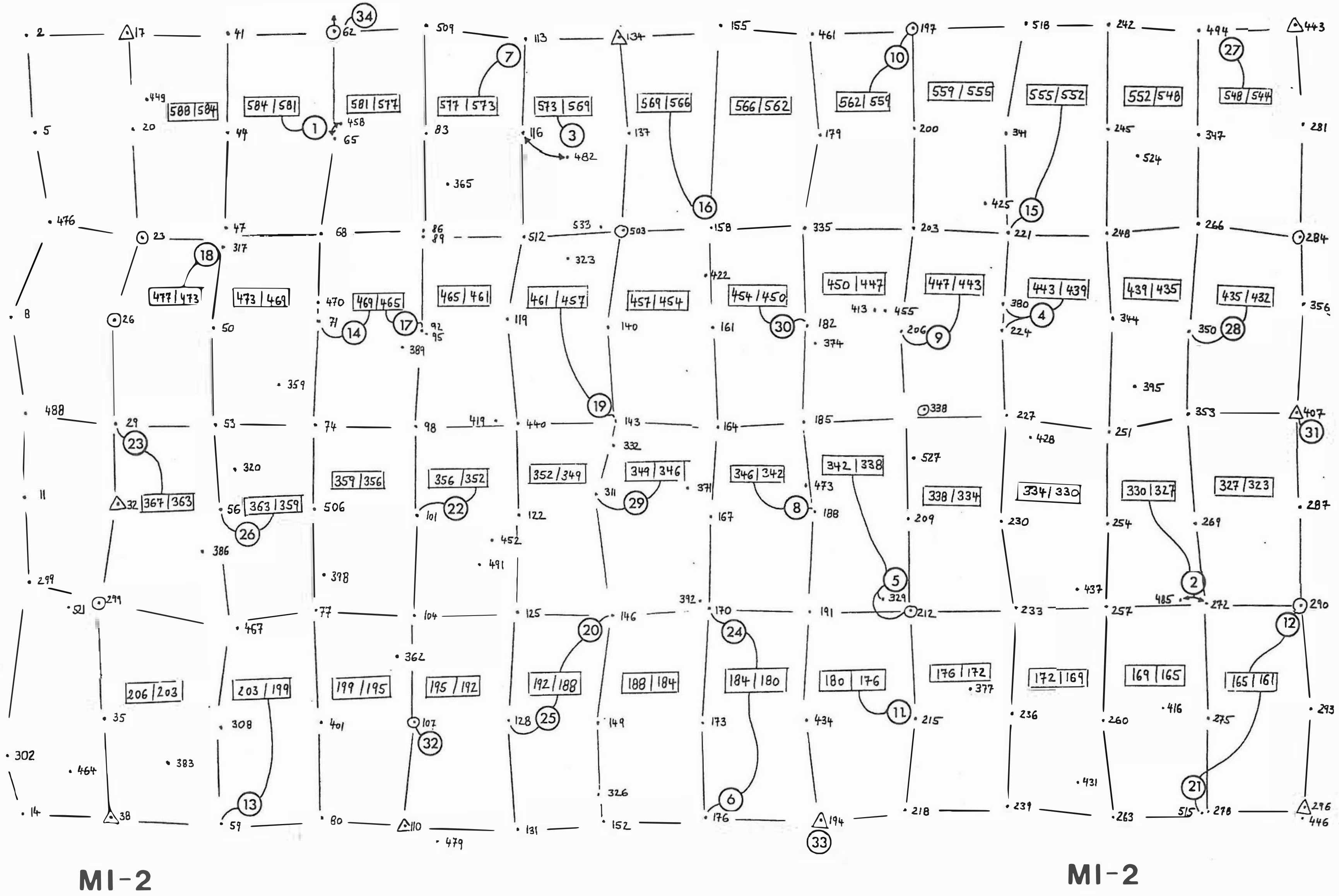
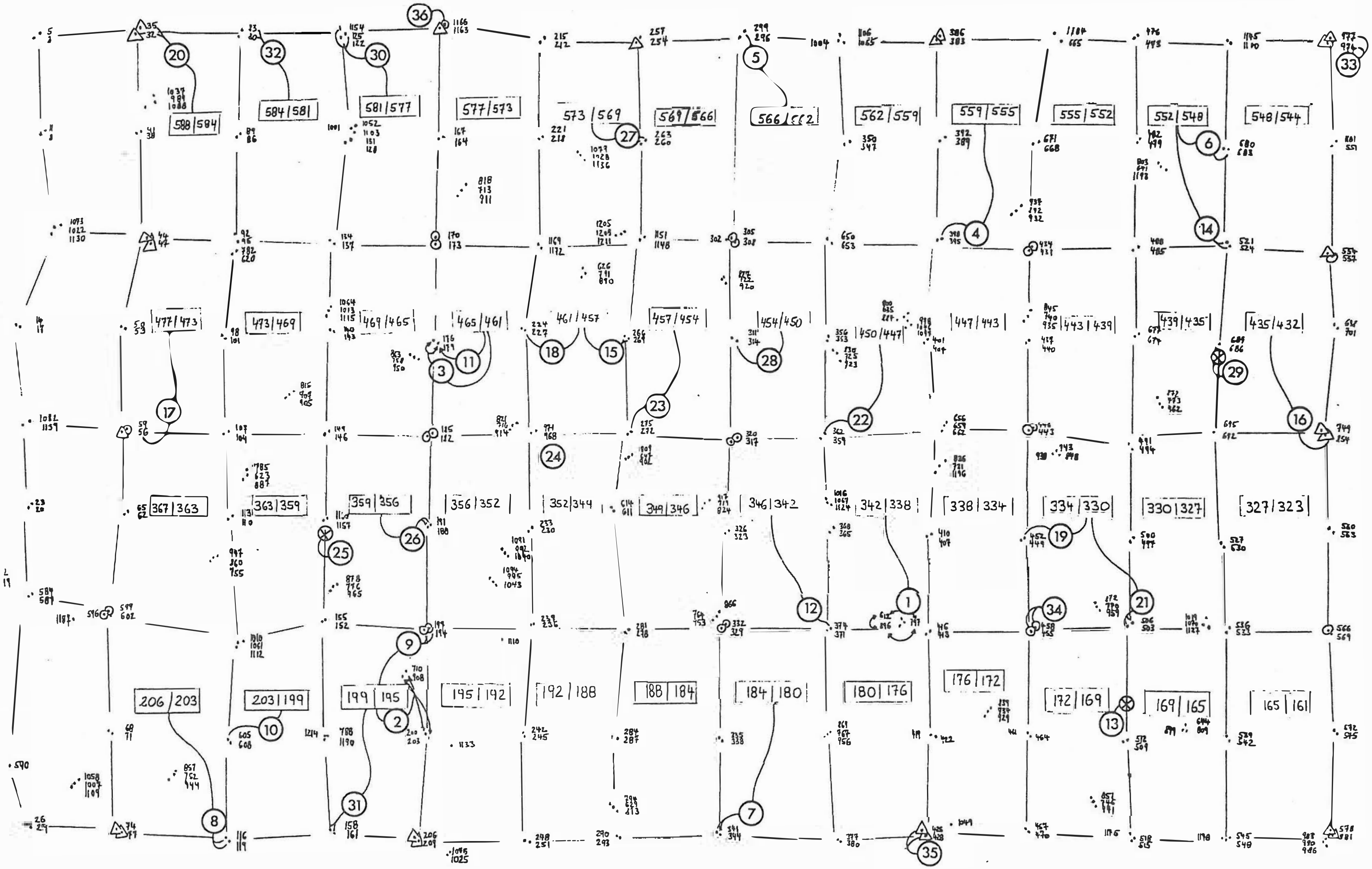
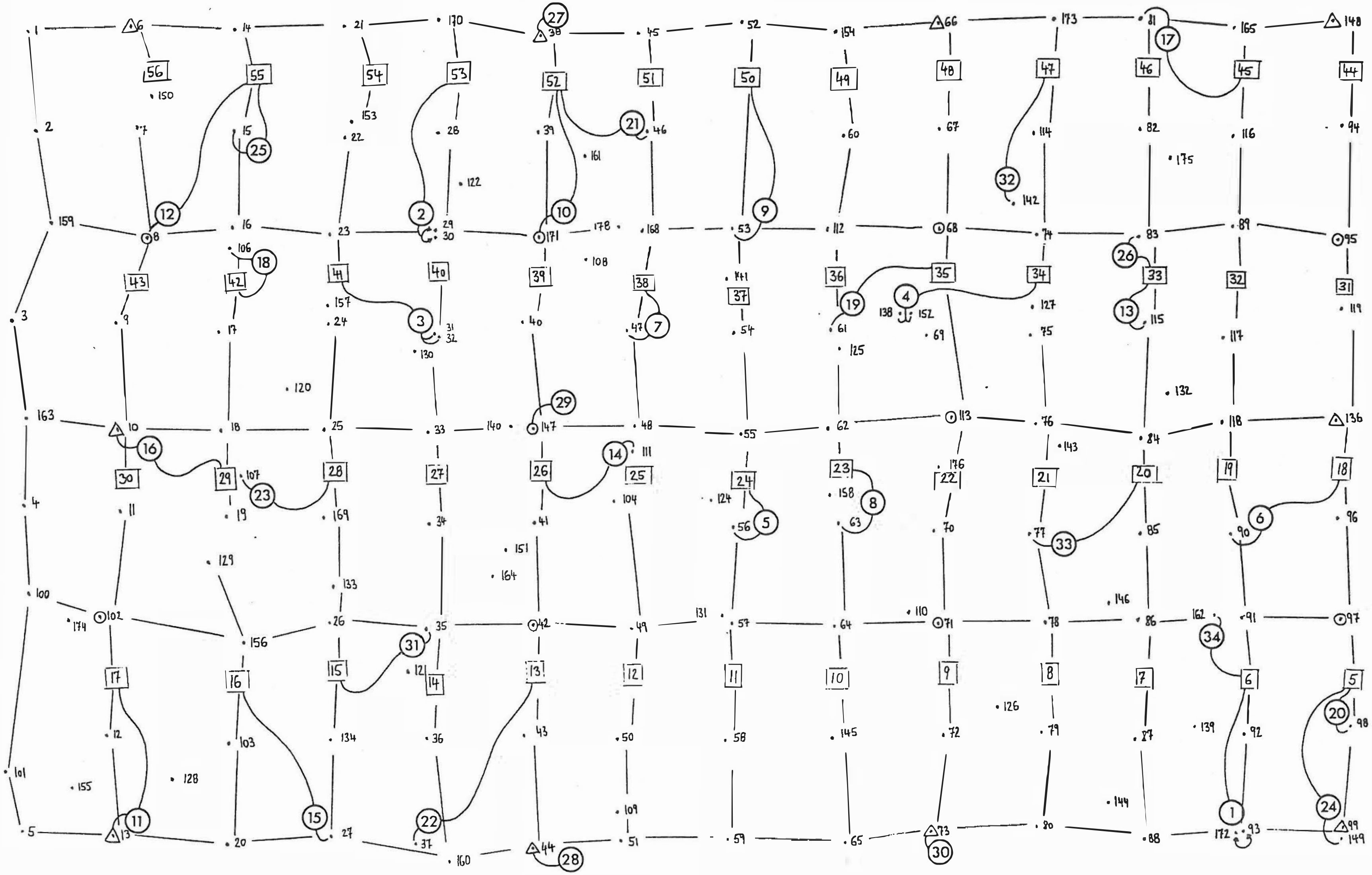


Fig. 6 Gross Errors inserted into Model Block MII/2 (cf. Tab. 13)



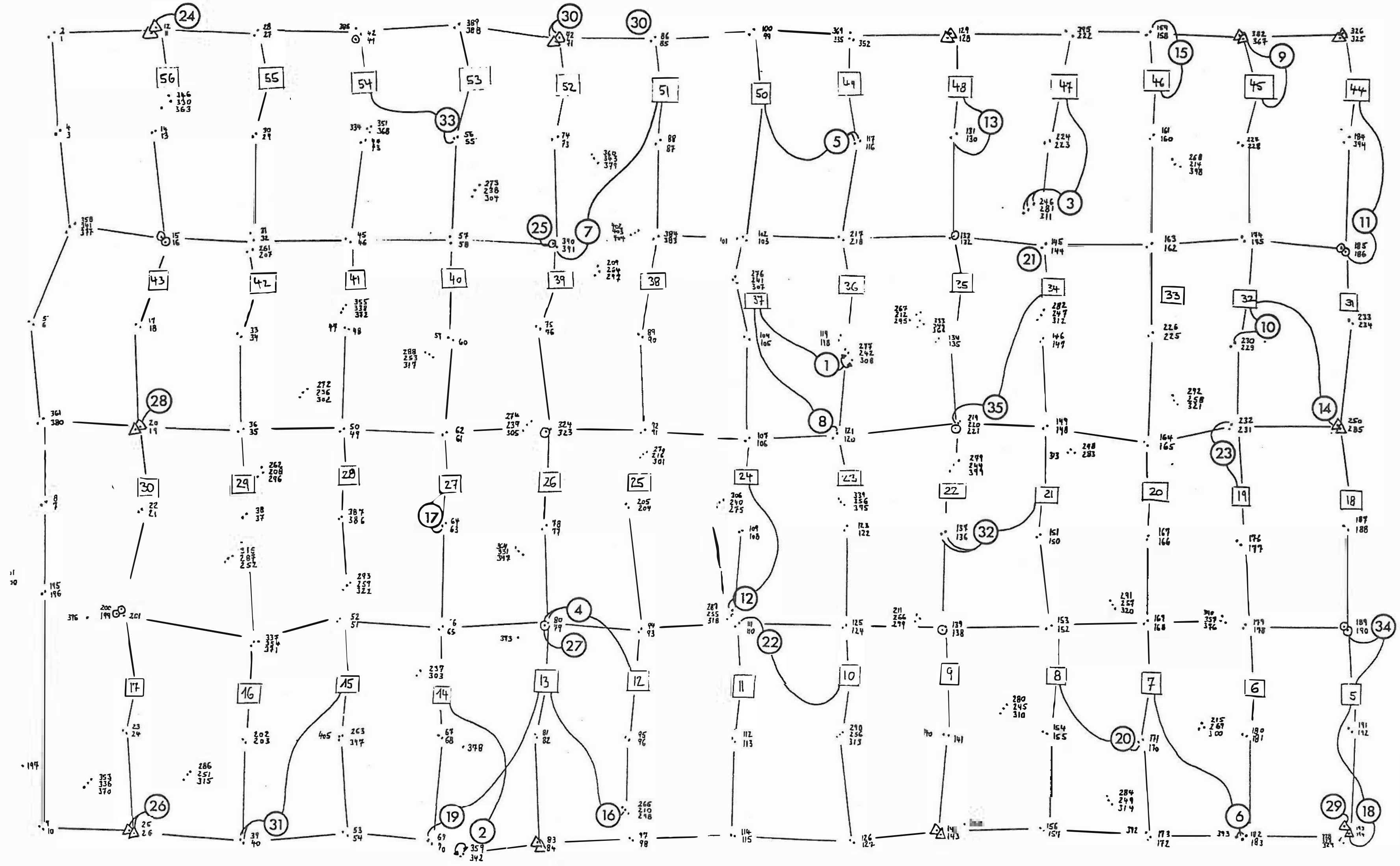
MII-2 **MII-2**

Fig. 7 Gross Errors inserted into Bundle Block BI/2 (cf. Tab. 14)



BI-2 BI-2

Fig. 8 Gross Errors inserted into Bundle Block BII/2 (cf. Fig. 15)



BII-2

BII-2

Fig. 9 Image Deformation of BII/1, strips 1 and 2

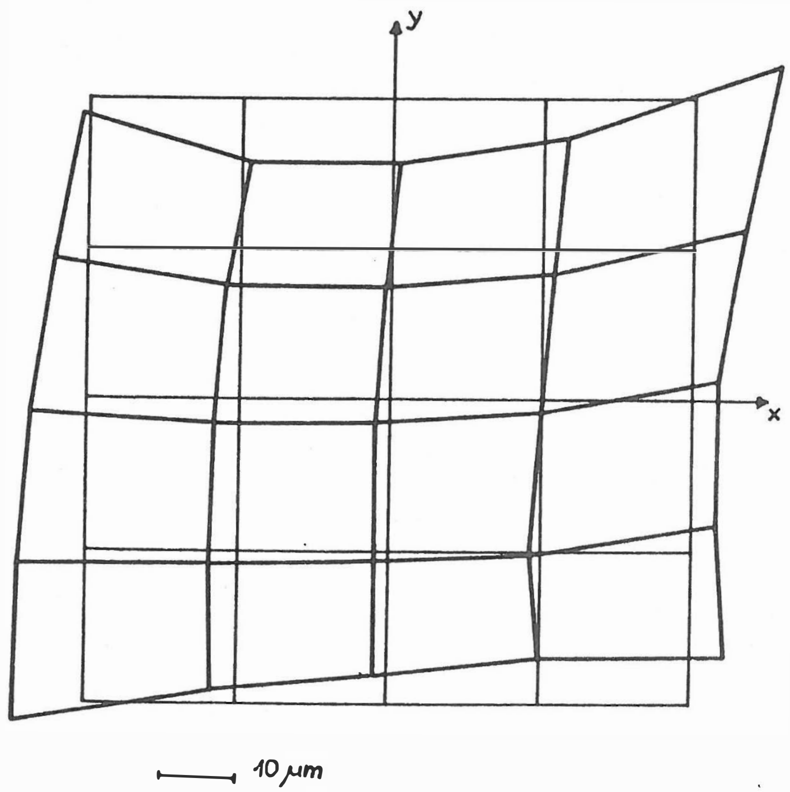
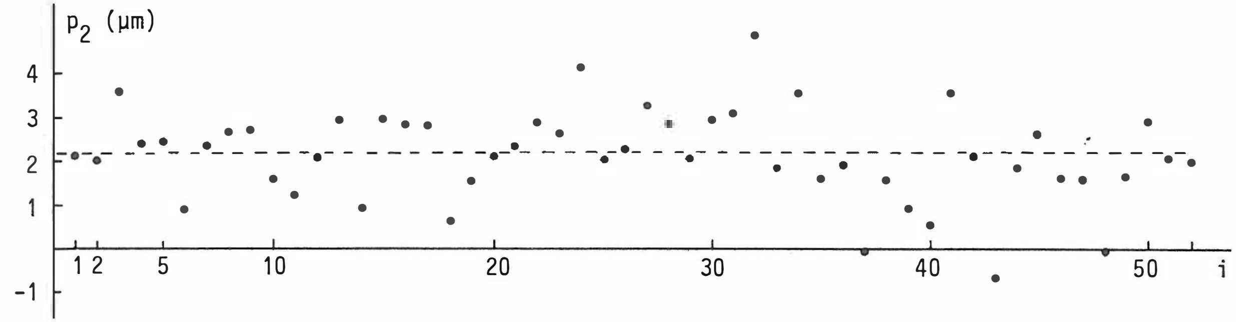
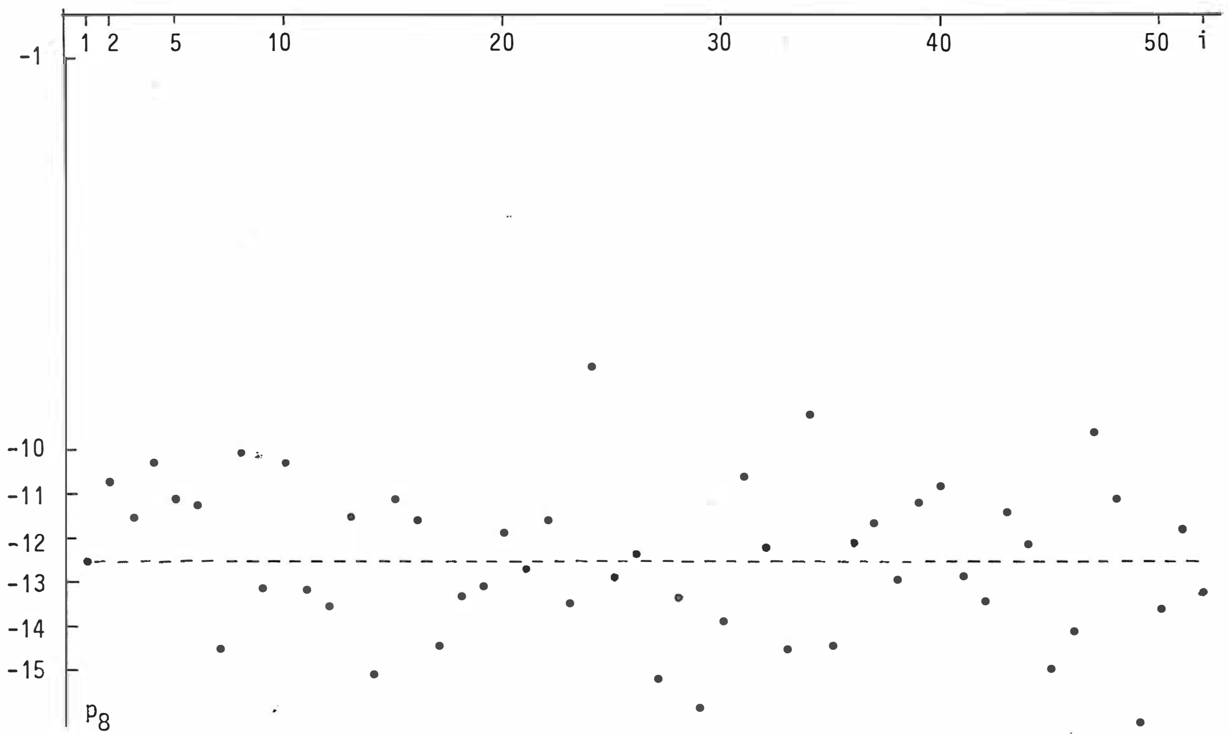


Fig. 10 Additional Parameters for Bundle Block BI/2

a)



b)



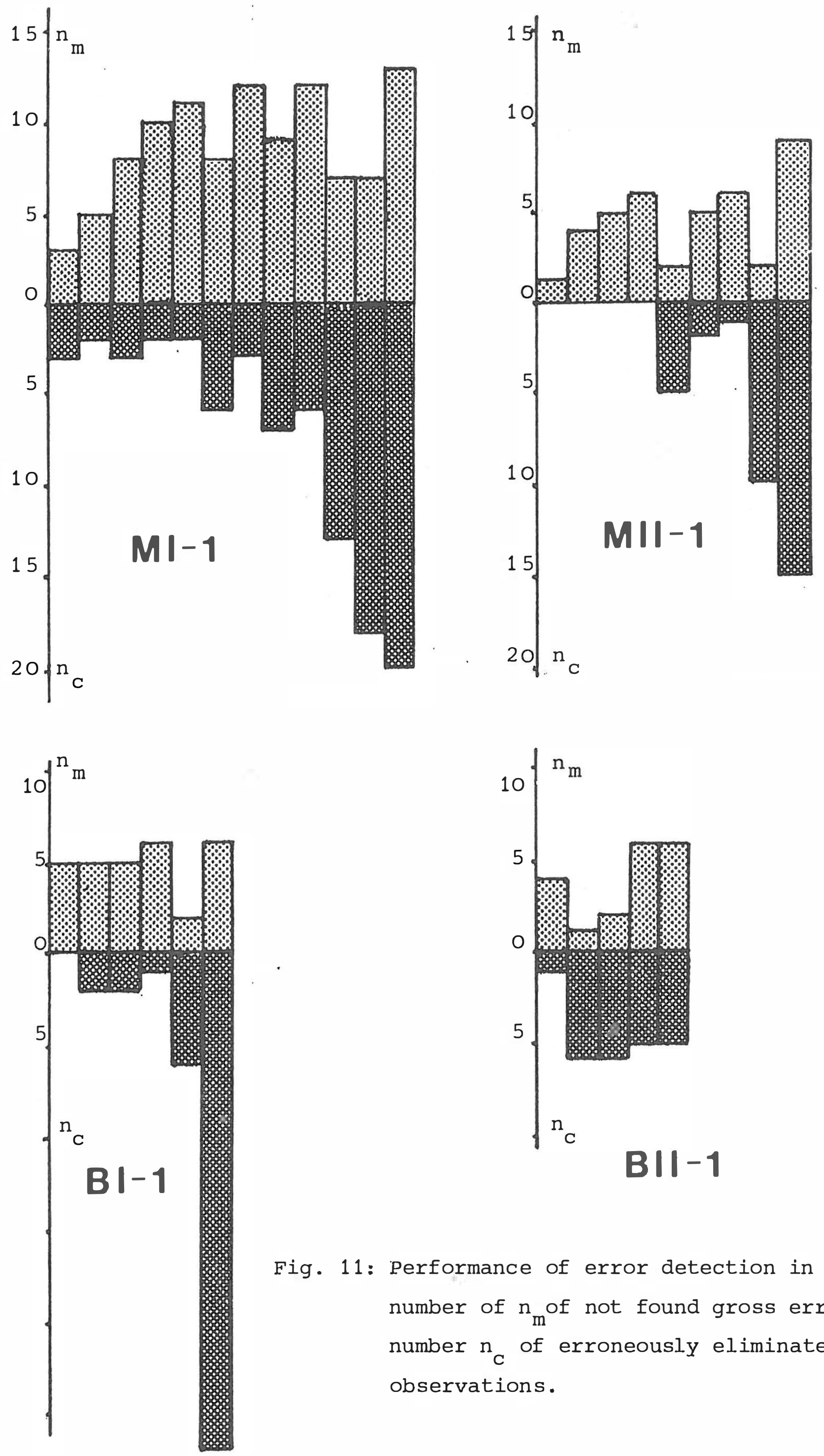


Fig. 11: Performance of error detection in phase 1 number of n_m of not found gross errors and number n_c of erroneously eliminated correct observations.

Fig. 12 Reactions on Gross Errors in Phase 1

corrected + eliminated o found - not found • wrongly corrected

MI-1

	1	2	3	4	5	6	7	8	9	10	11	12
1	#	+	+	+	+	+	+	+	+	+	+	+
2	#	+	+	+	+	+	+	+	+	+	+	+
3	#	#	+	+	#	#	#	#	#	#	+	+
4	#	#	+	+	#	#	#	#	#	#	#	+
5	#	#	+	+	#	#	#	#	#	#	#	+
6	#	#	+	+	#	#	#	#	#	#	#	#
7	#	#	+	+	+	−	#	#	#	#	#	−
8	−	−	−	+	+	+	−	−	−	−	−	−
9	#	+	+	+	#	#	#	#	+	#	#	#
10	#	#	+	+	#	#	#	#	#	#	#	+
11	+	+	+	+	+	+	+	+	+	+	+	+
12	#	#	−	−	#	#	#	#	#	#	#	−
13	#	#	−	−	+	#	#	#	+	#	#	#
14	#	#	+	+	#	#	#	#	#	#	#	#
15	−	−	−	−	−	−	−	−	−	−	−	−
16	−	+	+	−	−	−	+	+	−	+	+	−
17	−	−	−	−	−	−	−	−	−	−	−	−
18	−	#	−	−	−	−	−	−	−	−	#	−
19	+	+	+	+	+	+	+	+	+	+	+	−
20	+	+	+	−	−	+	+	+	+	+	+	+
21	+	#	+	−	+	•	#	#	#	#	#	+
22	−	+	−	−	−	−	#	#	−	−	•	−
23	−	+	−	+	−	−	−	−	−	−	−	−
24	+	+	+	−	−	−	−	−	+	+	+	+
25	−	+	+	−	−	−	+	+	+	−	+	−
26	+	+	+	+	+	+	o	o	+	+	+	+
27	−	+	−	−	−	−	+	+	+	−	+	−
28	−	+	+	+	−	−	−	−	−	+	+	−
n_m	10	3	9	12	11	12	7	7	8	8	5	13
n_c	2	3	7	6	2	3	13	18	6	3	2	20
I_p	12	6	16	18	13	15	20	25	14	11	7	33

MII-1

	1	2	3	4	5	6	7	8	9	10
1	#	#	#	#	#	#	+	#	#	+
2	#	#	#	#	#	#	o	#	#	#
3	#	#	#	#	#	#	#	#	#	+
4	#	#	#	#	#	#	+	#	#	#
5	#	+	+	#	#	+	+	#	+	+
6	#	+	+	#	#	+	+	+	+	+
7	#	#	#	#	#	#	−	#	#	+
8	#	+	+	#	#	+	+	+	+	+
9	#	#	#	#	#	#	#	#	#	#
10	#	#	+	#	#	o	+	#	#	+
(11)	.	.	.	.	.	.	.	.	.	.
12	#	#	#	#	#	o	#	#	#	#
13	#	+	+	#	#	+	+	•	+	+
14	#	#	#	#	#	+	+	#	#	+
15	#	#	o	+	+	+	o	#	#	−
16	#	#	#	o	o	#	o	#	#	#
17	#	#	#	#	#	#	+	#	#	−
18	−	+	−	+	+	+	+	−	+	−
19	−	−	−	•	•	−	−	+	+	−
20	+	−	−	+	+	+	+	+	+	−
21	#	#	#	#	#	#	+	#	+	−
22	−	−	−	+	+	−	+	−	+	−
23	−	−	−	−	−	−	+	#	+	−
24	−	−	−	+	+	+	+	−	+	−
25	−	2/3	1/3	2/3	2/3	−	−	−	−	2/3
n_m	6	5	6	2	2	4	2	5	1	9
n_c	0	0	1	5	5	0	10	2	0	15
I_p	6	5	7	7	7	4	12	7	1	24

BI-1

	1	2	3	4	5	6
1	#	#	#	#	o	+
2	#	#	#	#	o	#
3	#	#	#	#	#	#
4	#	#	#	#	#	#
5	#	#	#	#	+	−
6	#	#	#	#	#	#
7	#	#	#	#	+	+
8	+	•	+	o	+	o
9	#	#	#	#	#	#
10	#	+	#	#	+	+
11	−	−	−	−	−	−
12	−	+	+	−	+	+
13	−	−	−	−	+	−
14	−	+	+	+	+	−
15	+	+	+	+	+	o
16	+	+	+	+	+	+
17	−	−	−	−	+	−
18	+	+	+	+	+	+
19	+	+	+	+	+	+
20	+	+	−	+	+	−
21	•	•	•	•	−	o
n_m	6	5	5	5	2	6
n_c	1	2	2	0	6	27
I_p	7	7	7	5	8	33

BII-1

	1	2	3	4	5
1	#	#	#	#	#
2	+	#	#	#	#
3	+	#	#	#	#
4	#	#	#	#	#
5	#	#	#	#	#
6	#	+	+	+	+
7	#	#	#	#	#
8	#	#	#	#	#
9	+	#	#	#	#
10	+	#	#	#	+
11	−	−	−	−	−
12	−	+	o	−	−
13	−	+	+	−	+
14	+	+	+	+	+
15	o	+	−	o	−
16	+	+	+	o	−
17	o	#	#	#	#
18	−	+	+	−	o
19	+	+	o	o	+
20	−	+	+	−	+
21	−	+	+	−	+
22	+	#	+	+	+
n_m	6	1	2	6	4
n_c	5	6	6	5	1
I_p	11	7	8	11	5

n_m missed errors

n_c erroneously eliminated correct observations

$I_p = n_m + n_c$ Performance index (no. of wrong decisions)

Fig. 13   Statistics of Reactions on Gross Errors in Phase 1

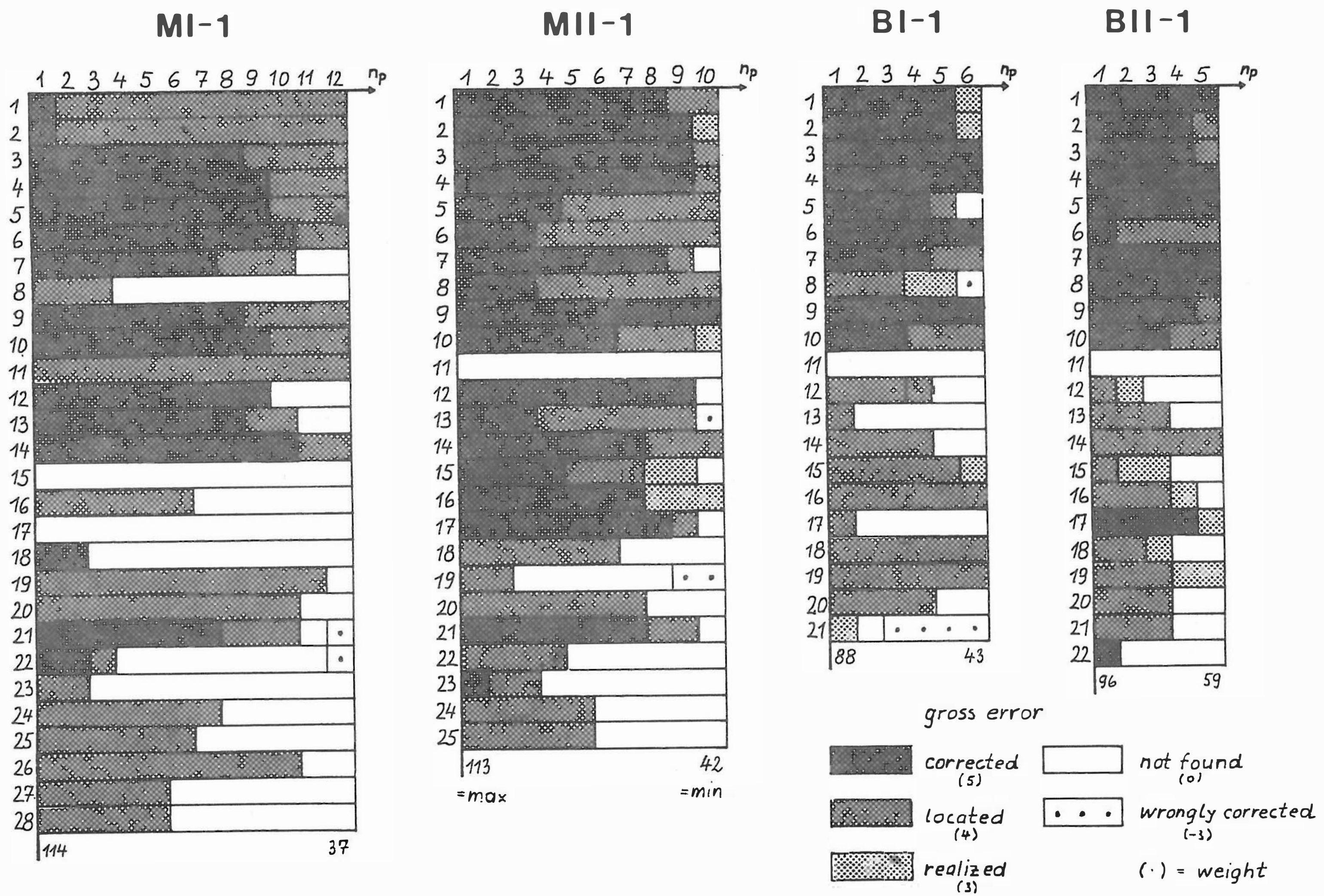
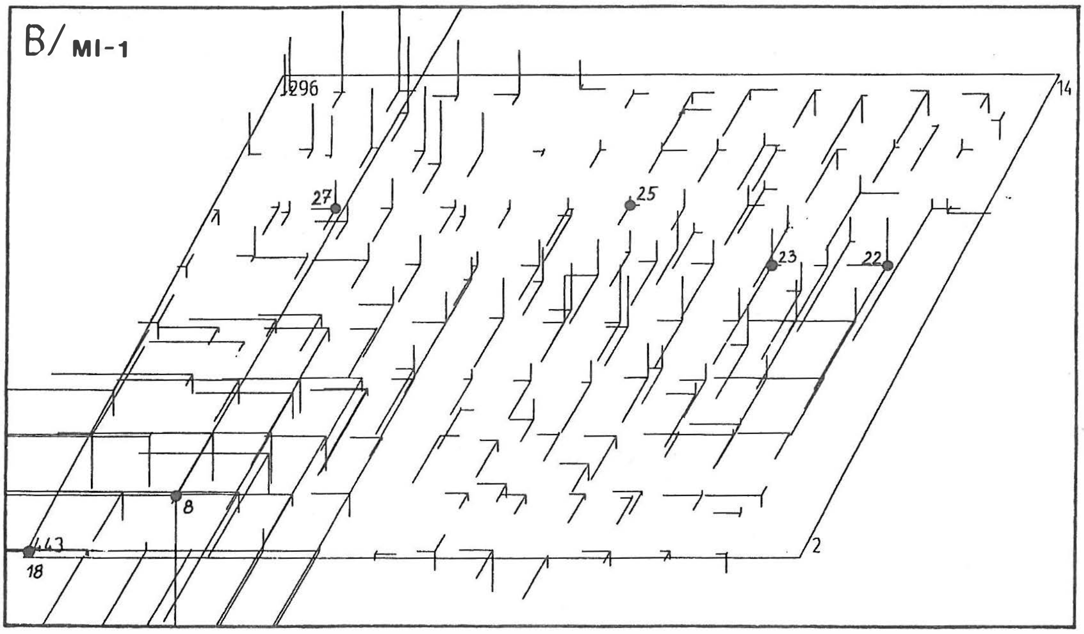


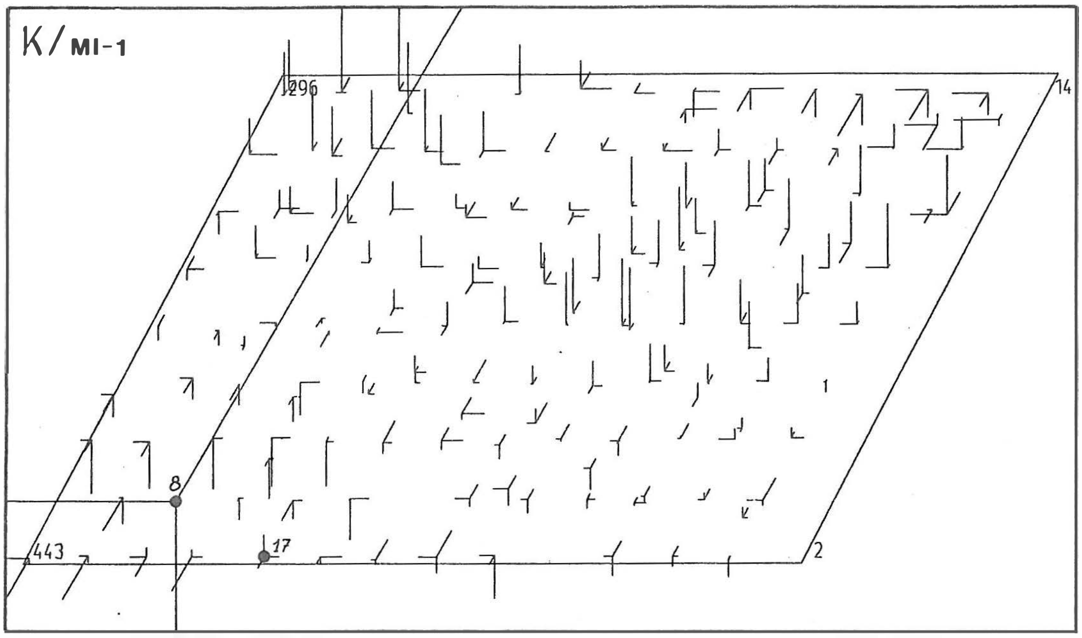
Fig. 14 True Errors of Model Blocks MI/1

a)



— entspricht 1 m

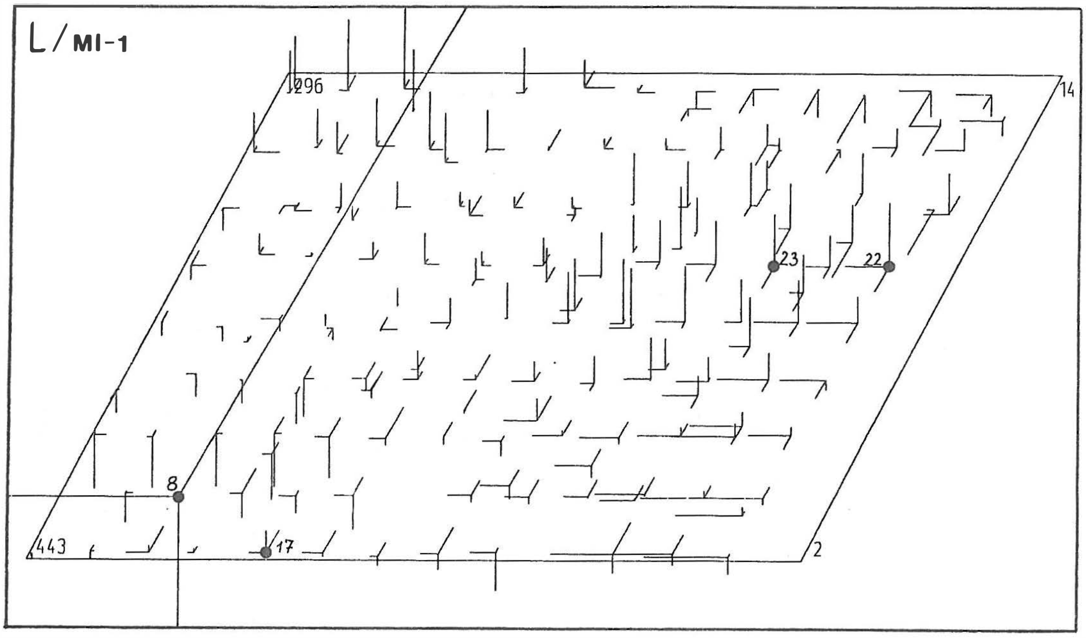
b)



— entspricht 1 m

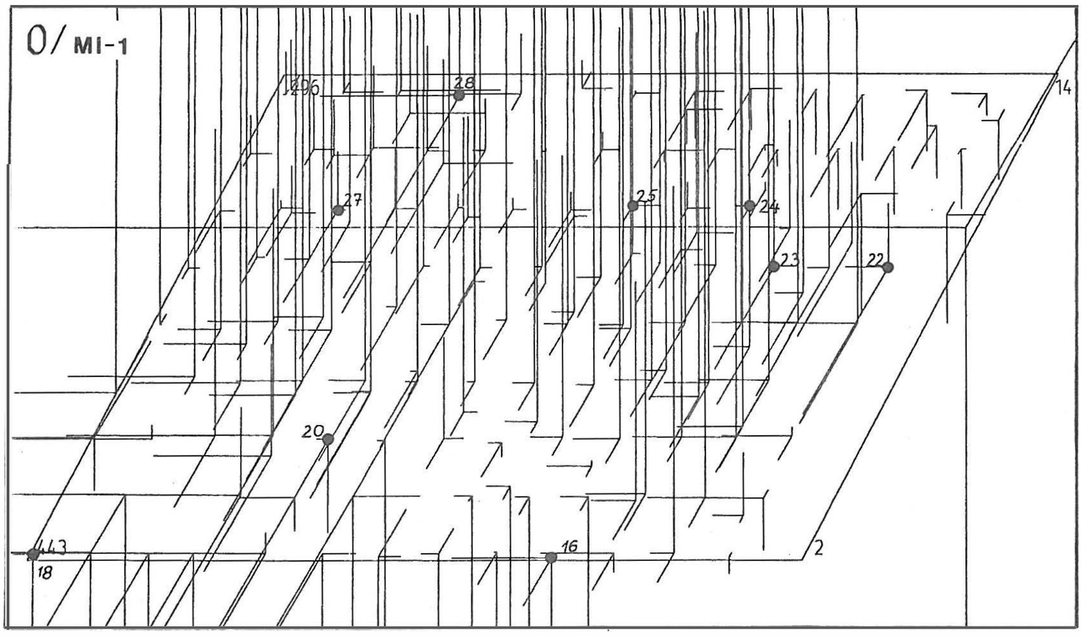
Fig. 14 True Errors of Model Blocks MI/1

c)



— entspricht 1 m.

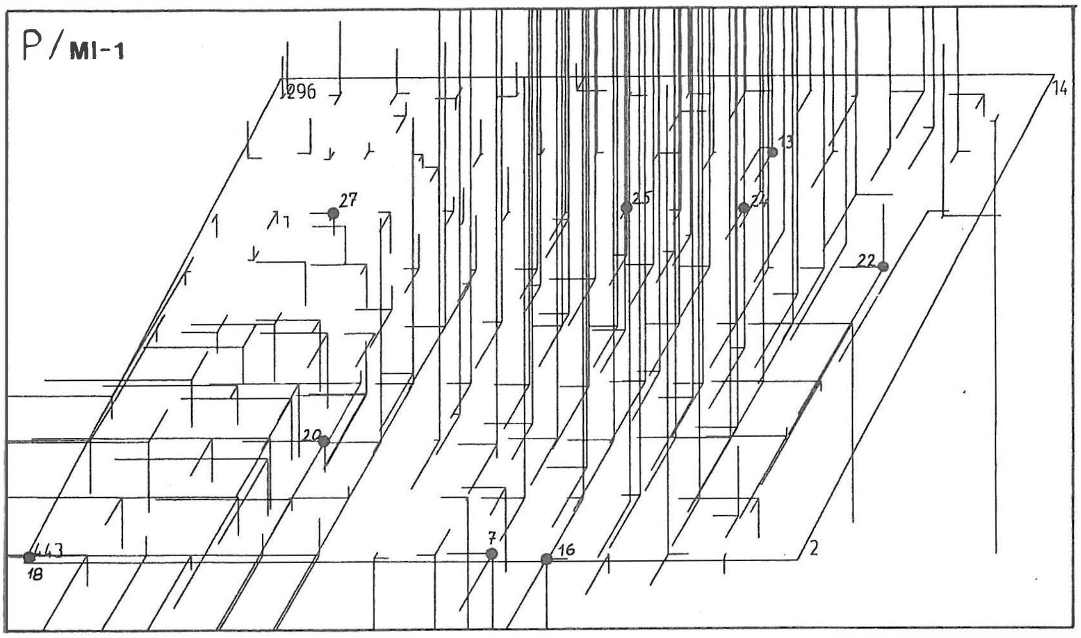
d)



— entspricht 1 m

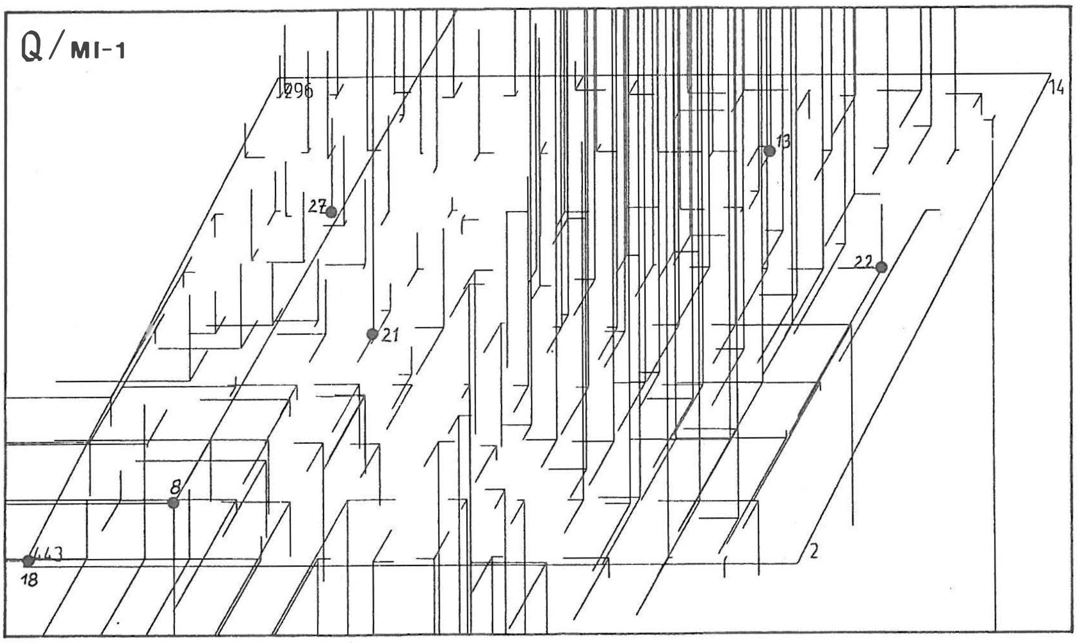
Fig. 14 True Errors of Model Blocks MI/1

e)



— entspricht 1 m

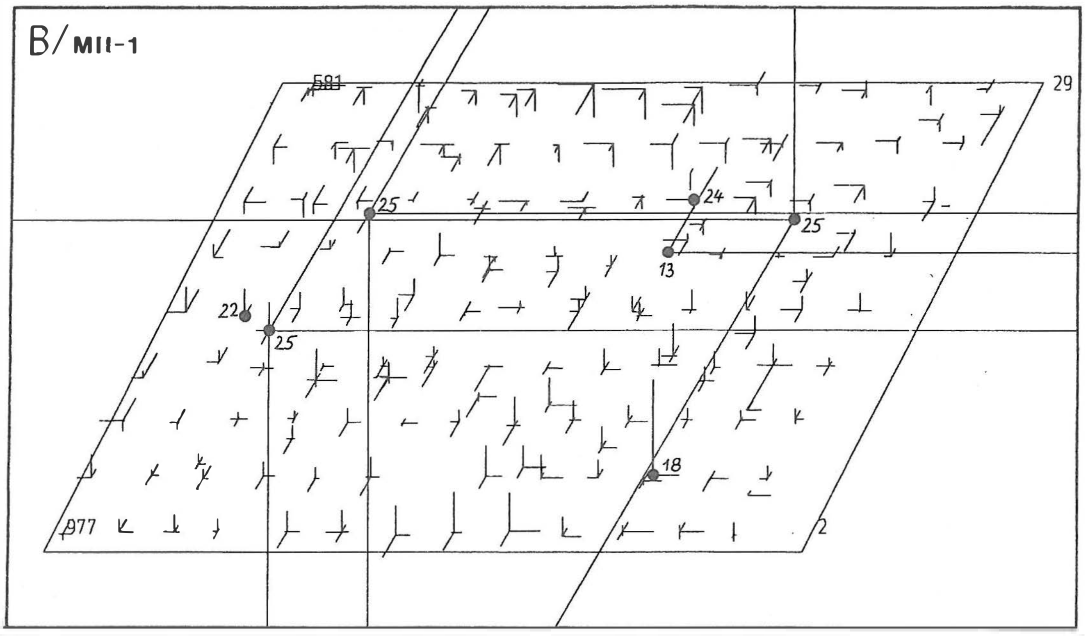
f)



— entspricht 1 m

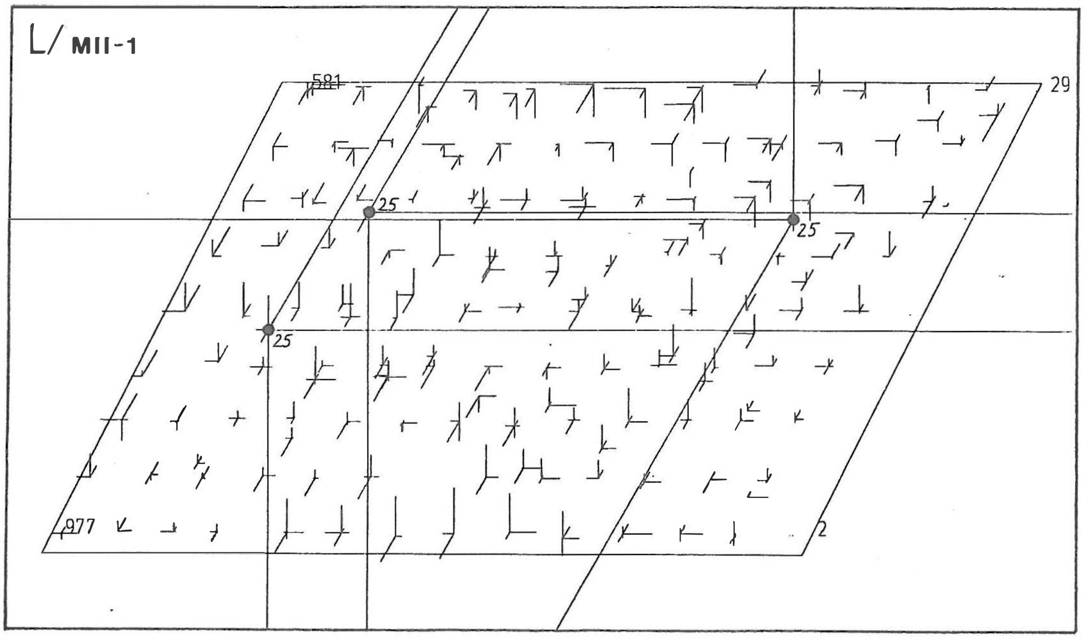
Fig. 15 True Errors of Model Blocks MII/1

a)



— entspricht 20 cm

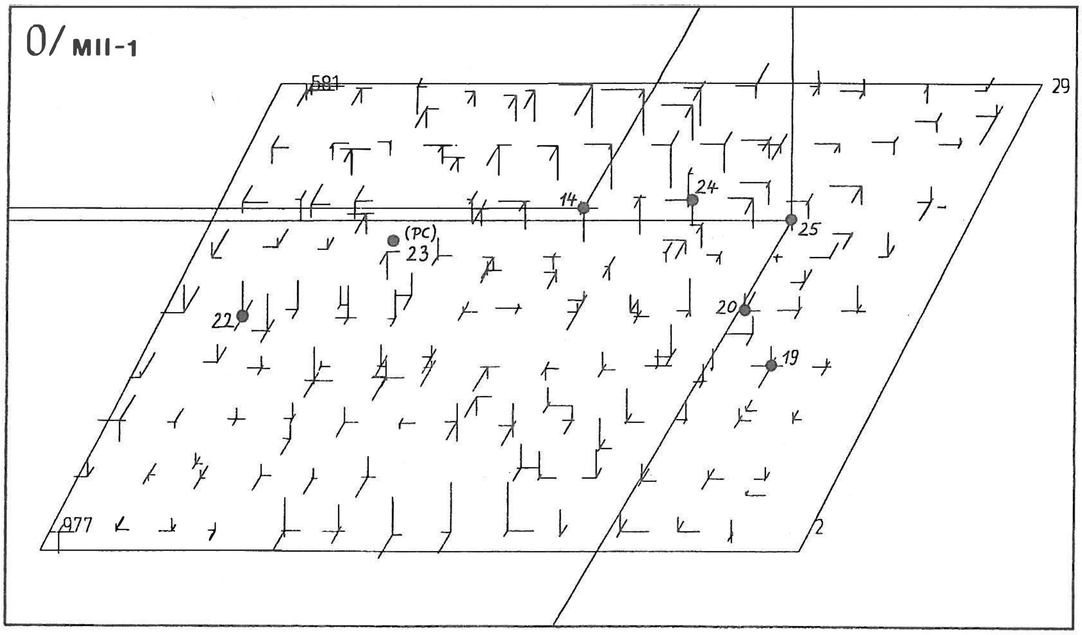
b)



— entspricht 20 cm

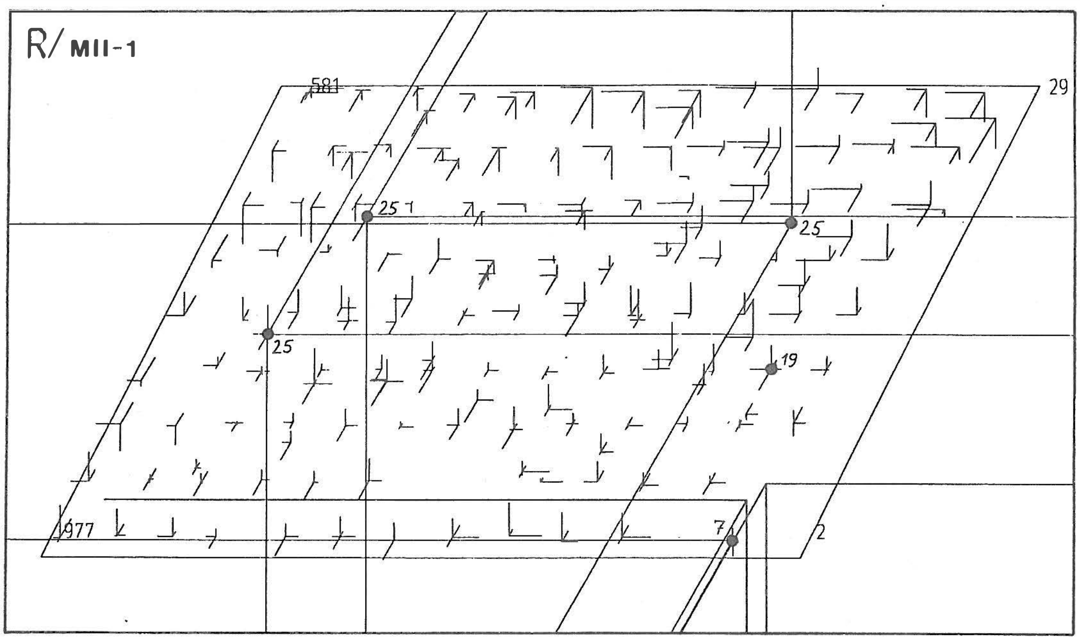
Fig. 15 True Errors of Model Blocks MII/1

c)



— entspricht 20 cm

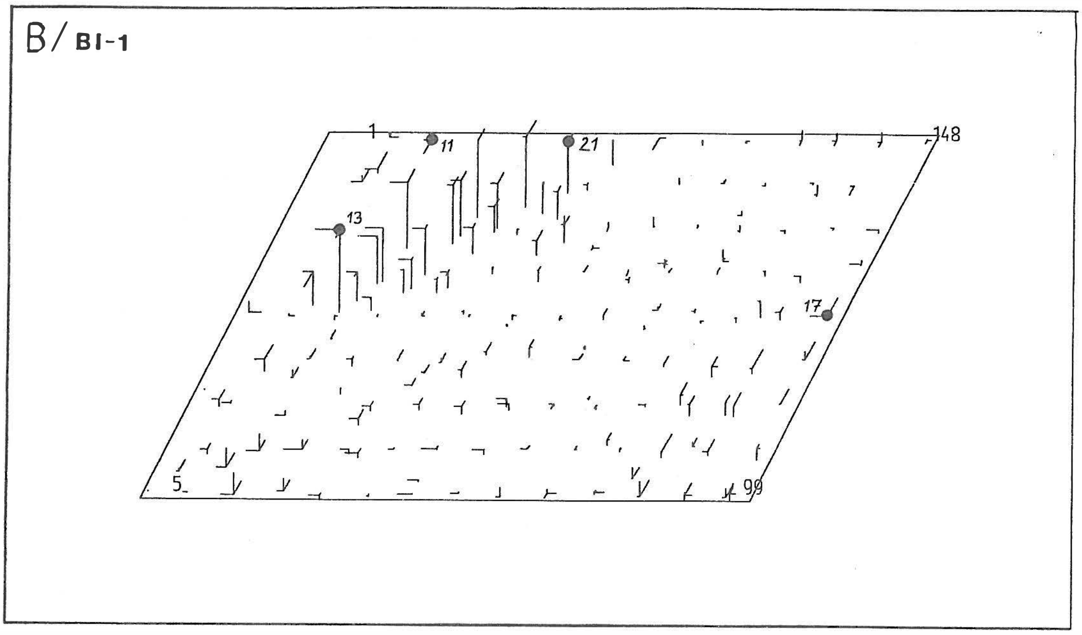
d)



— entspricht 20 cm

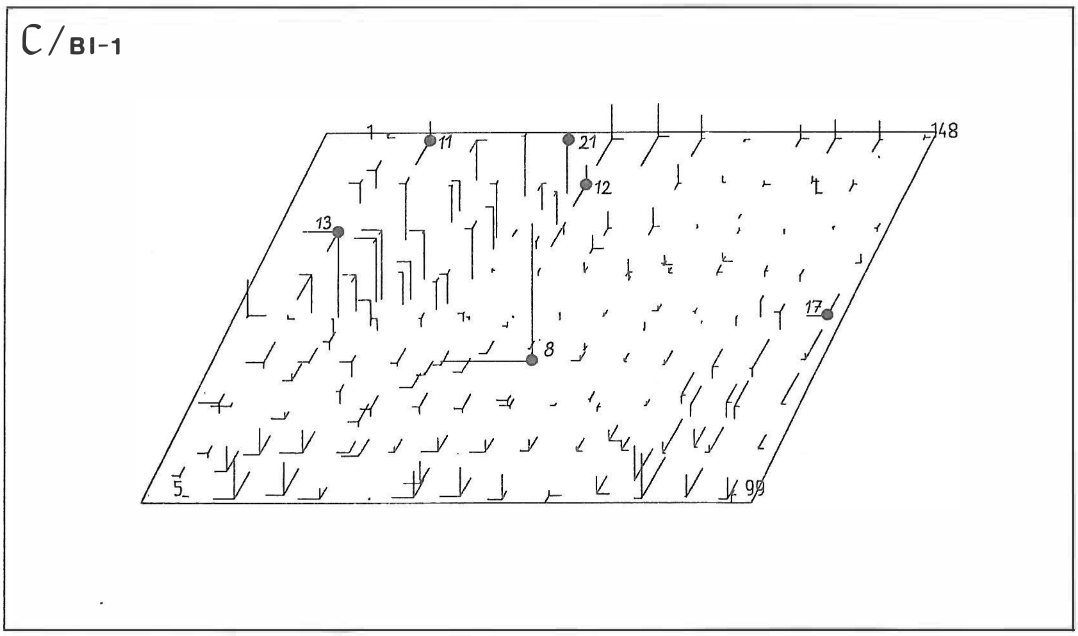
Fig. 16 True Errors of Bundle Blocks BI/1

a)



— entspricht 1 m

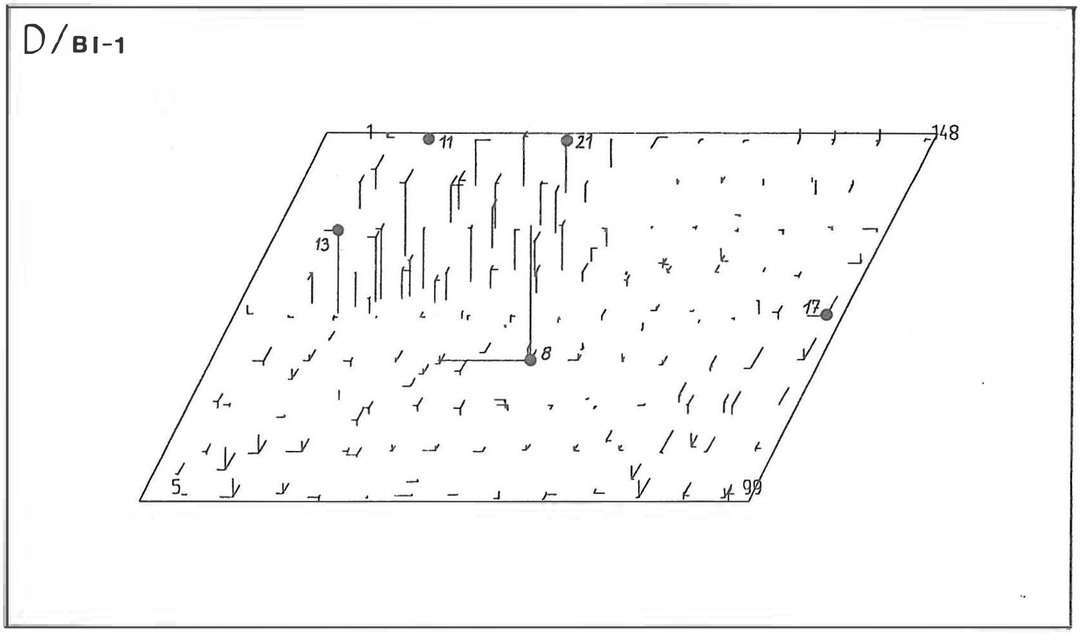
b)



— entspricht 1 m

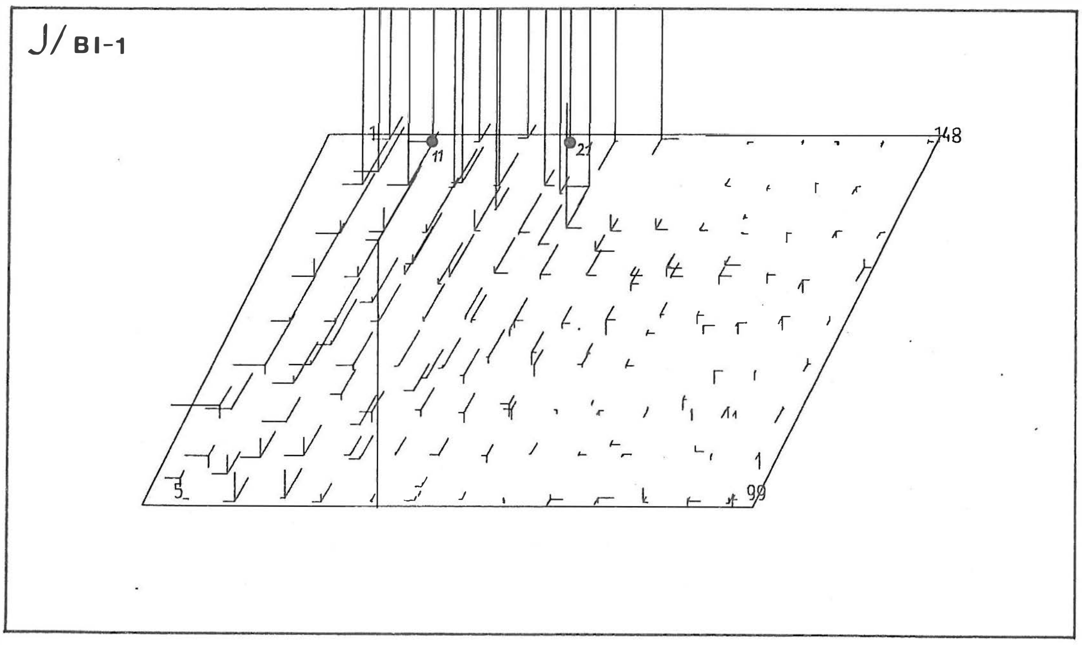
Fig. 16 True Errors of Bundle Blocks BI/1

c)



— entspricht 1 m

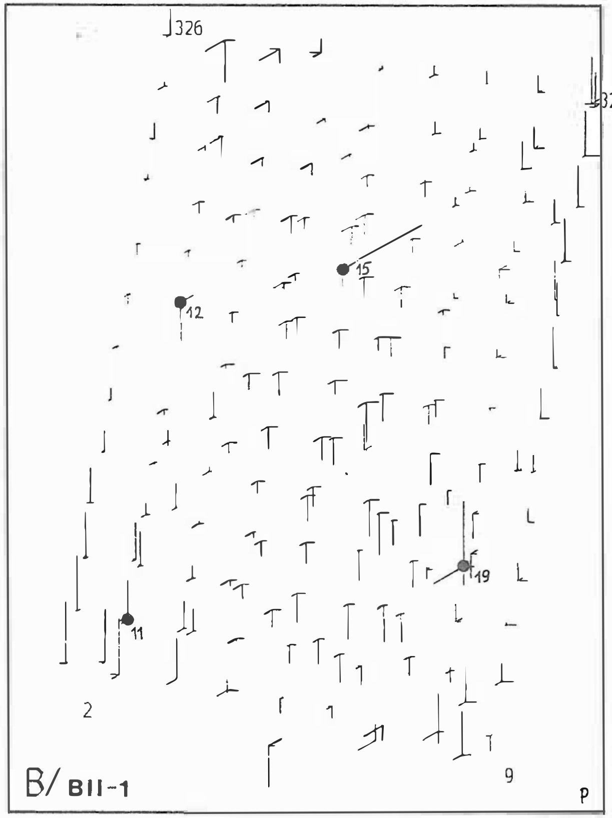
d)



— entspricht 1 m

Fig. 17 True Errors of Bundle Blocks BII/1

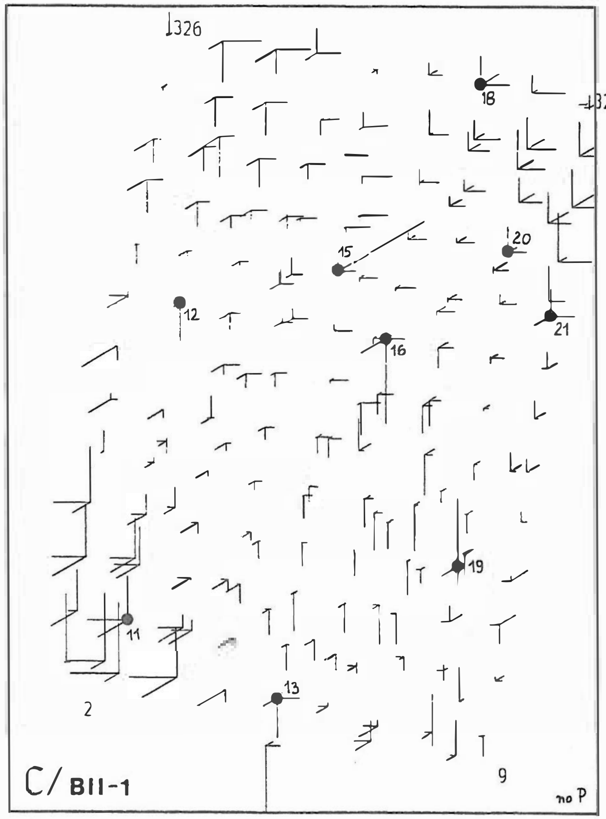
a)



μ_{xy} = 0.05 m μ_z = 0.17 m

— entspricht 20 cm

b)

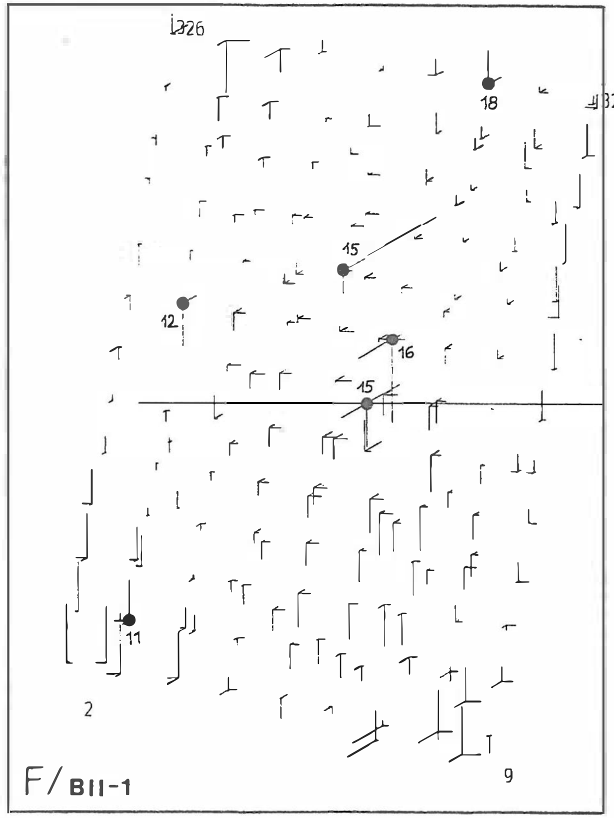


μ_{xy} = 0.12 m μ_z = 0.18

— entspricht 20 cm

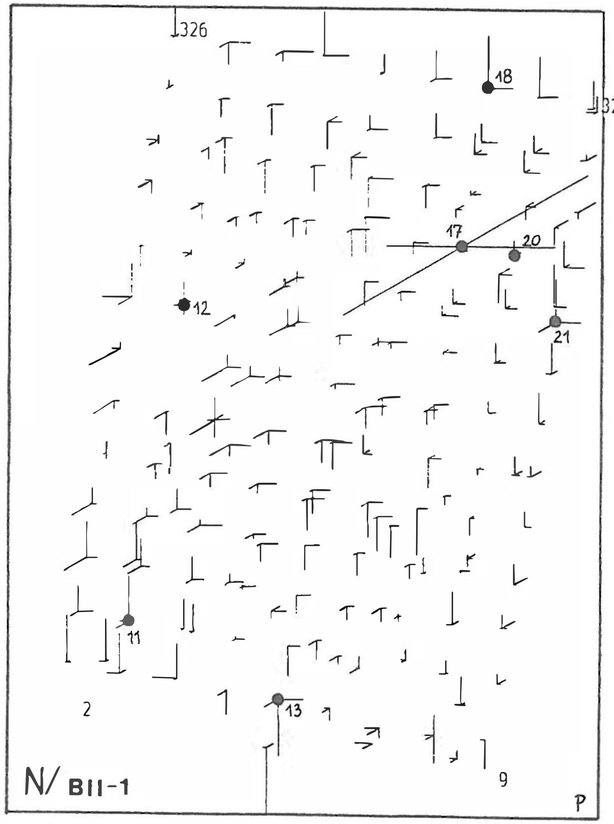
Fig. 17 True Errors of Bundle Blocks BII/1

c)



— entspricht 20 cm

d)



— entspricht 20 cm

Fig. 18 Empirical and Theoretical Efficiency of Practical Procedures (cf. Tab. 26)

Extreme (———) and mean (------) values for probability E (%) of error detection

Curve = Theoretical efficiency

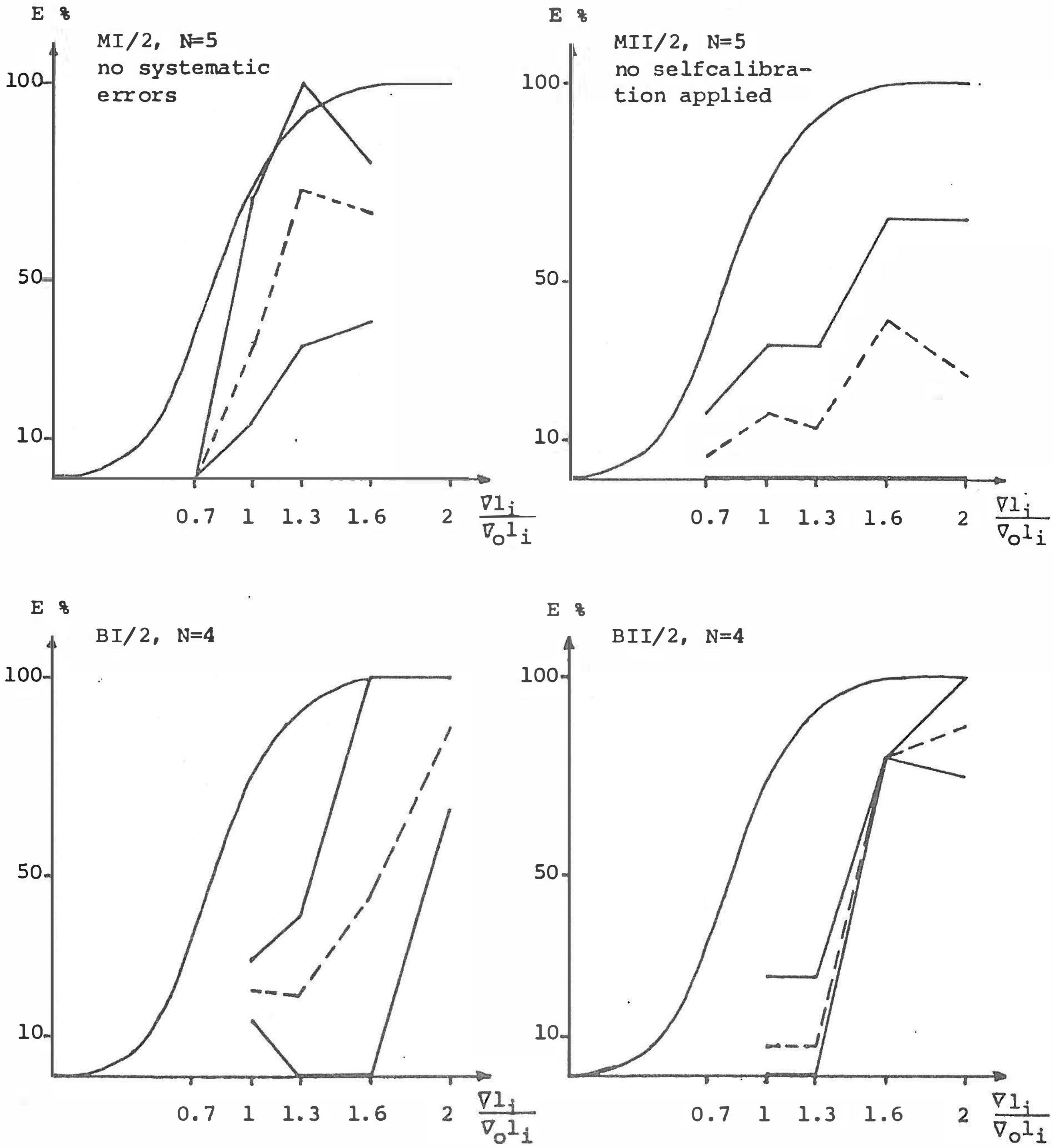
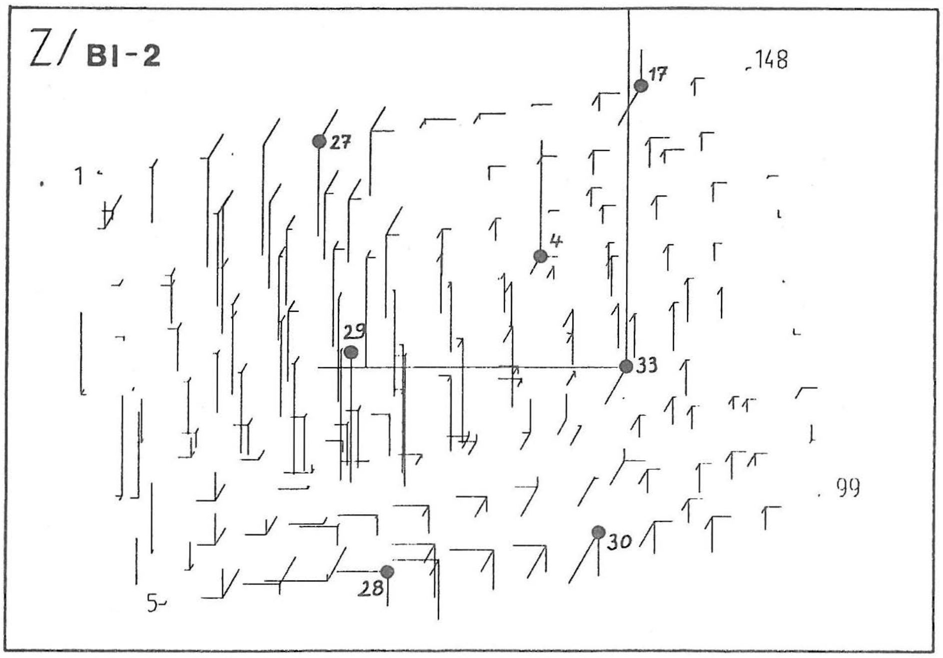


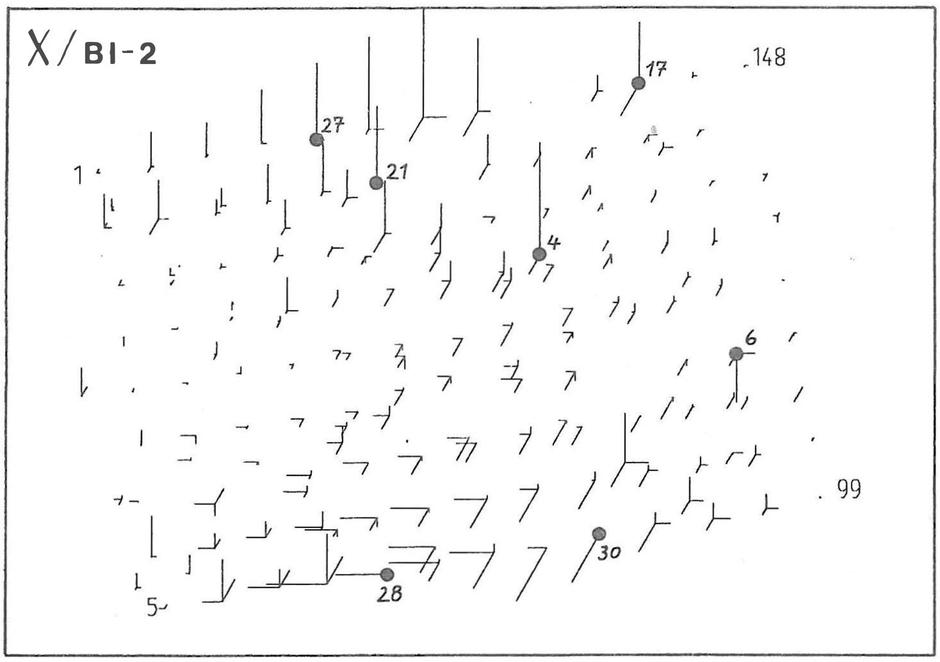
Fig. 19 True Errors of Bundle Blocks BI/2

a)



— entspricht 1 m

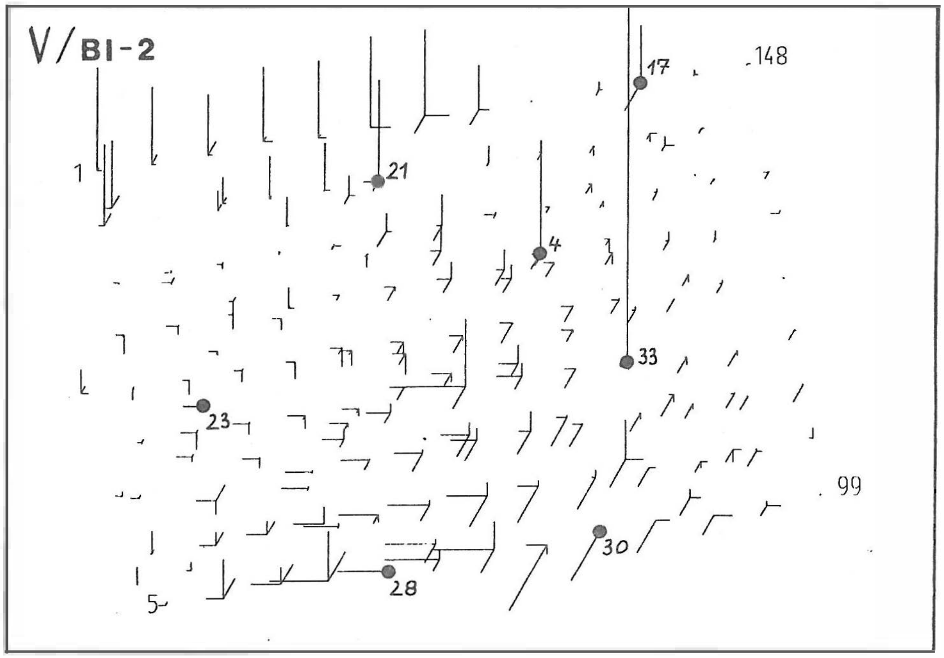
b)



— entspricht 1 m

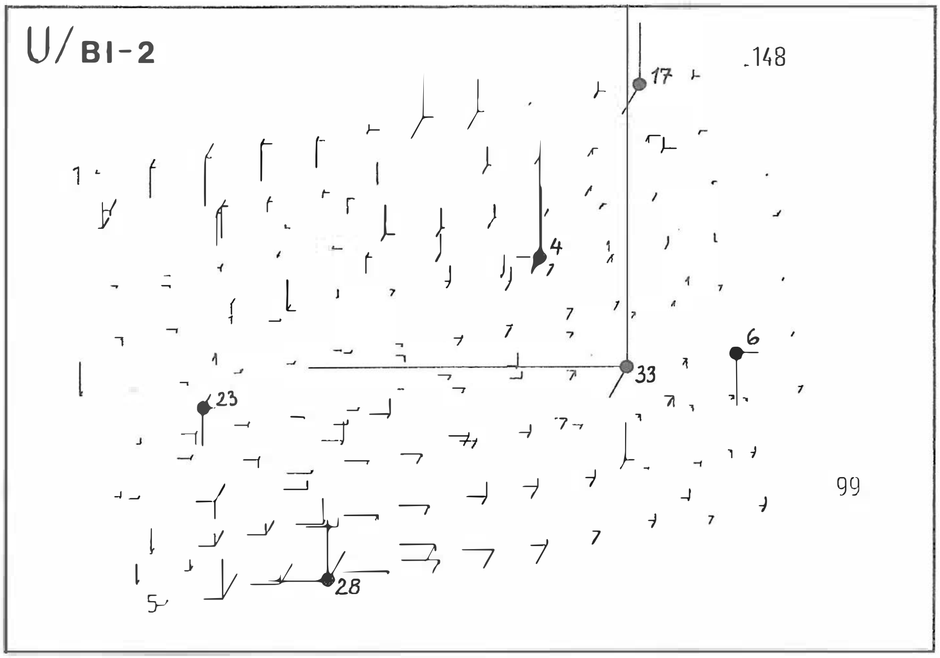
Fig. 19 True Errors of Bundle Blocks BI/2

c)



— entspricht 1 m

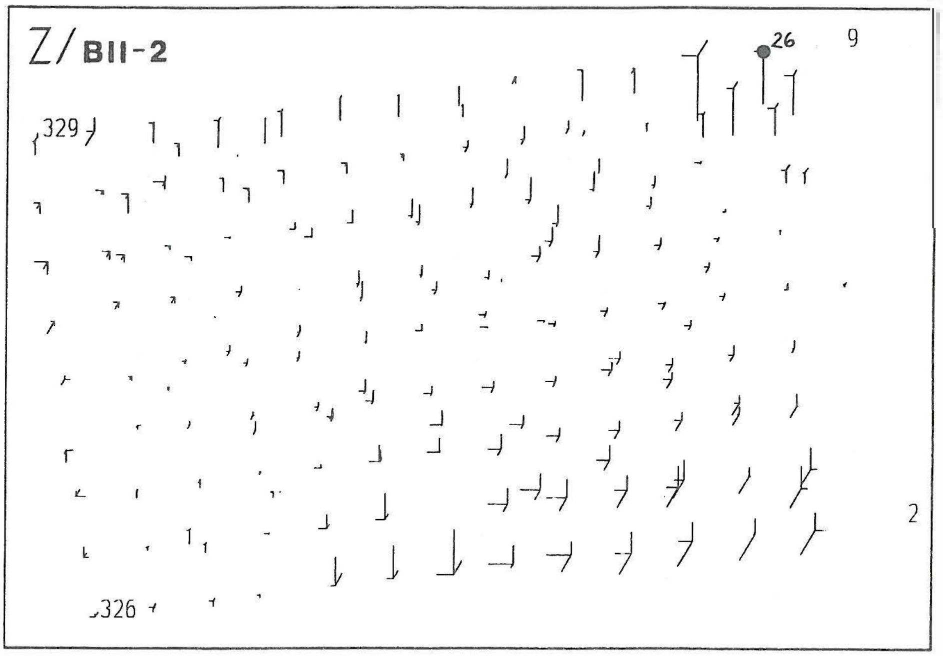
d)



— entspricht 1 m

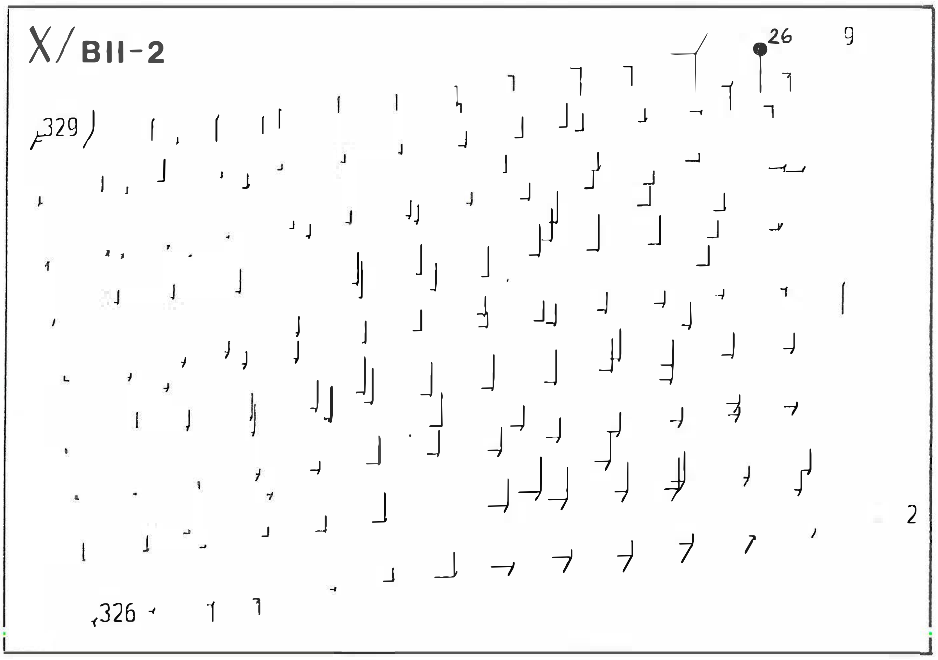
Fig. 20 True Errors of Bundle Blocks BII/2

a)



— entspricht 20 cm

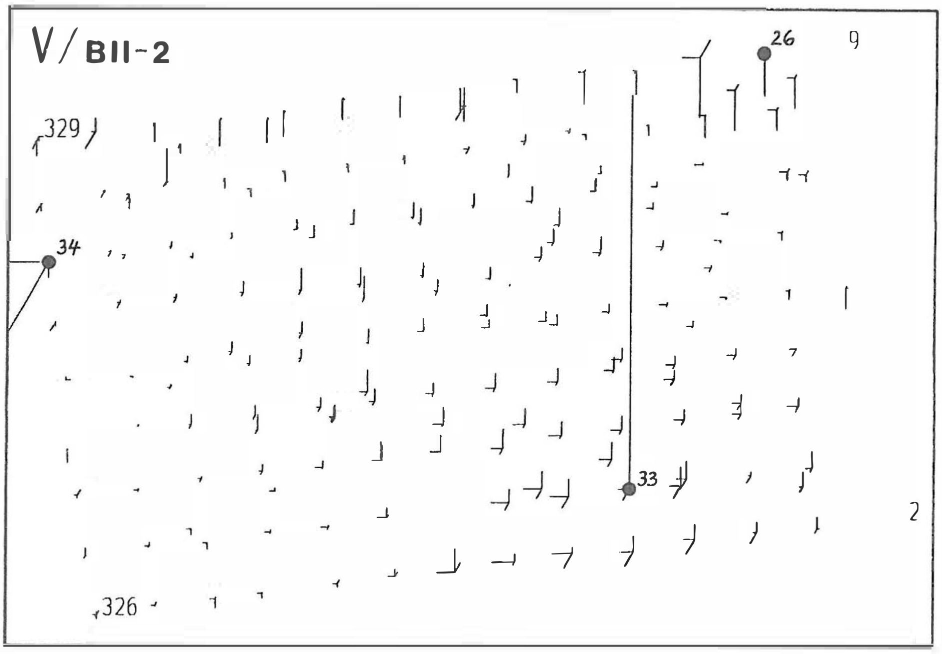
b)



— entspricht 20 cm

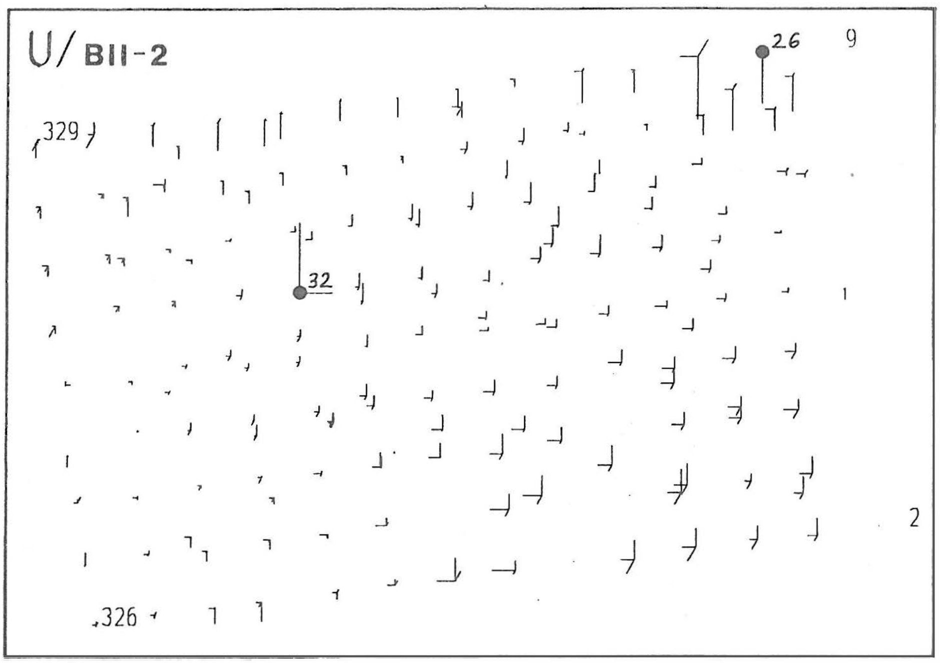
Fig. 20 True Errors of Bundle Blocks BII/2

c)



— entspricht 20 cm

d)



— entspricht 20 cm