6. CONCLUSIONS

1. The Boilerselection-program is a valuable tool for the design and evaluation of new boilerplants for space heating in buildings.

2. The Boilerselection-program has been verified with measurement in an existing boilerplant; the agreement between reality and simulation is good.
Techniques modernes en matière de mètreage et de calcul par ordinateur à la recherche, au calcul et à la présentation des données précises d'une construction conçue avec la méthode de calcul aux états limites (b.a.e.l.)

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MOTS-CLÉS:
Méthode de calcul aux états limites (b.a.e.l.) Implantation, fichier de données, (recherche, calcul et présentation) écarts de position et de dimension, déformation d'éléments portants sous charge

SOMMAIRE:
En Suède l'on a introduit, sur une base à l'heure actuelle volontaire mais obligatoire avant 5 ans, une nouvelle réglementation relevant de la méthode de calcul aux états limites (b.a.e.l.). SIB à établi sur un chantier, les conséquences géométriques de son application dans la pratique. Cette étude sur le terrain - la première en son genre - comporte deux parties, à savoir:
- Détermination des écarts dus par ex à l'implantation ou au coffrage
- Détermination des écarts de construction en tant que conséquences possibles de la réglementation

Dans ces deux domaines de recherche il a été fait appel pour la collecte du plus grand nombre possible de données précises, aux techniques de mètreage les plus modernes. L'une d'entre elles était la méthode des "points de stationnement libres". Le système de coordonnées locales A, B et C du chantier a servi de référence pour le levé détaillé et le calcul de valeurs précises dans les différents cas. Les différents points des coordonnées étaient matérialisés par des voyants dressés dans les caniveaux principales autour du chantier.

L'avantage du recours, en ce type d'études, à des systèmes de coordonnées, réside dans le fait que d'autres déviations ou écarts tels que par ex les écarts de verticalité, d'épaisseur, de centrage, d'inclinaison, de rectitude ou d'aplatissement peuvent facilement être déterminés par l'ordinateur à partir des écarts de position constatés.

Après la mise en mémoire des données, l'on calcule les paramètres statistiques. Les résultats peuvent être présentés graphiquement de différentes manières: par des histogrammes, des diagrammes de cycles ou des lignes de contour faisant apparaître directement le degré d'aplatissement par ex d'une dalle de plancher en sa totalité. Le document informe de même sur les différentes possibilités d'utilisation de l'ordinateur en matière de recherche et de collecte de données précises.

L'on s'attache à ce que l'application de la nouvelle réglementation exige davantage de précision qu'à l'heure actuelle. Le présent document contient donc des exemples des quelques précisions intéressantes et des commentaires par ex sur la façon d'améliorer cette précision. Une telle amélioration n'exige pas nécessairement le recours aux procédés les plus modernes de mesure ou des techniques de production. Une meilleure communication entre le chantier et les bureaux est plus importante.

ACCURACY DATA OF A STRUCTURE DESIGNED ACCORDING THE LIMIT STATE DESIGN METHOD

John van den Berg, Ake Lindberg

1 BACKGROUND

New safety regulations for load-bearing structures have been introduced in Sweden. They are based on the limit state design method. The application of them is not compulsory yet, a free selection between the traditional and new ones has been allowed during a period of about 5 to 7 years.

Changing from well established and familiar routines may of course meet some problems and hesitations, at least in the beginning. The National Swedish Institute for Building Research (SIB) therefore decided to investigate whether there are any significant consequences or difficulties when applying these new regulations. Of importance here is also the answer to the question about the role of dimensional and measuring accuracy, since it is expected that accuracy requires still more attention than at present.

2 THE AIM OF THE STUDY

The field study, which is the first of its kind, had two goals:
- Determining position-, dimension- and form deviations and comparing them with the tolerances in the new regulations.
- Determining actual deformations of the structure or parts of it and comparing them with the calculated ones, to check the adopted calculation method.
- Obtaining general information about the achieved accuracy when using modern production- and measuring methods.

The secondary goal was:
- To get a starting point for the development of guide lines for deformation measuring procedures in building, included in the working program of ISO/TC 59/SC 4.
- To get a clear picture of the alternative uses for the computer in the collection - and presentation of accuracy data.

3 DESCRIPTION OF THE PROJECT

The object which was selected is an extension of a 15 year-old building. The extension is a four storey building with basement and attic. (See Fig 1.)

The Foundations - a slab on undisturbed bearing stratum -, the bearing walls, columns and the beam and floor slabs are of in-situ concrete. The external walls consist of facing brick tied into the bearing concrete walls having insulation in the cavity. Non-loadbearing internal walls are of plasterboard, attached to steel frames.

The formwork was of plywood. In the case of the floor slabs, the plywood was supported by beams and struts, while for the walls it was attached to a frame of aluminium, shuttered in 4-8 metres long and storey height, sections.
4 SCOPE OF THE STUDY

The field study was concentrated to a certain section of the structure. The reason for doing so was that the following two conditions had to be fulfilled.

* During construction work:
  To be able to collect accuracy data of the same important coherent parts and details of the structure, when using local coordinates (see § 5).
* After construction work:
  To be able to gain access to the same measuring points, as used during construction time, when determining short- and long-term deformations.
  (Since the object in question is a hospital it is obvious that a following up of deformations can hardly be carried out everywhere.)

5 REFERENCE SYSTEMS

The collection of accuracy data implies the handling of quite a number of measuring values, such as distances, directions and levels. From these quantities other quantities have to be calculated e.g. positions, verticalities, eccentricities deflections, thickness and heights. With computer aided collection it is convenient to express the actual position of every measured point in coordinates of a local A, B and C system, with the axis parallel with the main reference lines of the building project. A, B and C coordinates can easily be derived from the running dimensions on the drawing.

The reference A and B coordinates, used in this study were represented by points in the primary system (figure 1), which was established around the site and connected to the municipal X and Y coordinate system. The C coordinates were levelled from master- and transferred bench marks, of which the levels were obtained from the public survey.

6 MEASURING- AND CALCULATION METHODS

6.1 Primary net

Prior to the collection of accuracy data of the structure the primary net, established and measured by a consulting firm, was remeasured to investigate whether its accuracy was sufficient as a reference for the forthcoming measuring procedures.

6.2 Reference bench marks

Bench marks were checked by means of precision levelling. For the transfer of bench marks to higher floors the levelling staff was replaced by a calibrated tape, provided with a tension device and the measuring values were corrected for temperature.

6.3 A and B coordinates of measuring points

For the determination of the A and B coordinates, the method of "Free station points" was applied as follows. The theodolite was set up arbitrarily in the vicinity of the points or lines to be measured-in. Its position coordinates were determined by redundant resection towards four points in the primary system and with the aid of a preprogrammed HP 41C. The HP also calculated the direction into which the theodolite had to be turned to get its sighting axis parallel to one of the axes of the local coordinate system. The shortest offset distances between the sighting axis and selected points on the structure were measured in with a rod (Figure 2). Investigations on the Mørtsbo test field showed that a measuring accuracy of $s = 1.3$ mm can be achieved.

![Figure 2](image)

Figure 2. The principles of the collection of accuracy data with the method of free station points. In this diagram the measuring-in of the position of the bearing walls.

6.4 Calculation of accuracy data

The measuring values obtained on the site, were stored in the central computer of the Institute, a Vax 11/780, and with the INFO program filed into registers. Since the position of every measuring point was known in coordinates, deviations from position, verticality etc (see § 5) could easily be calculated. With the general program 3P5X the statistical parameters were taken out.
5.5 Presentation of accuracy data
With the program SPSS-graphic, accuracy data can be graphically presented in different ways, e.g., histograms, circle diagrams, contour lines.

7 ACCURACY DATA

7.1 Primary net
Primary nets are usually connected to official nets, and according to the recommendation in ISO 4463, by only one connecting point and direction. By doing so inaccuracies in the official net will be eliminated. The standard specifies acceptance criteria for the accuracy of primary nets. The one applied in this section concerns: "When distances and angles, derived from given coordinates (here by the consulting firm), have to be compared with those determined by a compliance measurement".

Example:
Distance calculated from the coordinates: 31.356 (PP 54-56)
Compliance measured distance: 31.363 see figure 1
Deviation:
Permissible deviation: \(2 \sqrt{L} \times 1.5 \sqrt{L}\) \(7\) mm
Angles calculated from the coordinates: 145.1342 gon (PP 56-55-9)
Compliance measured angle: 145.1237 gon
Deviation:
Permissible deviation: \(0.15 \sqrt{L} \times 0.10 \sqrt{L}\)
\(0.0106\) gon
\(0.0268\) gon (0.0179 gon)
\(L = \) the shorter of the two distances, defining the angle

\(x\): According to the draft proposal of ISO 4463 revised.

Comments on § 7.1
ISO 4463 recommends that the establishment of primary nets has to be planned with great caution. This is a normal accuracy precaution in quality control. This is of not done because "good time" is seldom available on site, or it has not been thought of, or for competition reasons found to cost too much. Neglecting the recommendation can become expensive. Figure 1 as an example shows some very acute angles of intersection, which could even have been detected by just a "quick look" at the plan and corrected accordingly. This accident caused an inaccuracy of about 30 mm, but as a piece of good luck located in the section direction, used in the setting out, instead of perpendicular to it, thus reducing the risk of serious setting out errors.

The accuracy of the other distances and angles fulfilled the criteria in ISO 4463 very well.

7.2 Bearing walls (thickness 160 mm)

7.21 Position deviations
The histogram in figure 3 shows the distribution of the position deviations of the finished walls, measured on a 2x1.5 metre spaced grid. The deviations are due to those in setting out and shuttering, but also to deformations of the formwork which occurred during concreting.

The permitted position deviation was: ± 20 mm.

Of the observed deviations were: 99% less than 20 mm, 1% exceeded the PD by 1 mm
82% less than 10 mm

The sector diagram in figure 4 presents the proportion of setting out, shuttering and deformations on the final result. This information could be achieved by measuring in the positions points for the formwork, set out by the contractor, the formwork itself and finally the walls after striking the formwork.

Figure 4. Proportion of setting out (I), shuttering (II) and formwork deformations (III) in the position deviation of the walls

Figure 3. Walls, position deviations in the position deviation of the walls

7.22 Verticality deviations (= a part of the shuttering deviations)
Since the measuring values from the grid points were expressed in A, B and C coordinates, the computer could easily calculate the verticality deviations.

The permitted verticality deviation was ± 12 mm
Of the observed deviations were: 98% less than 12 mm, 2% exceeded the PD by 2 mm
80% less than 5 mm.

Comments on § 7.21 and 7.22
The accuracy reported above can be considered as normally achievable.

7.23 Eccentricity
With the aid of the A, B and C coordinates obtained on the different floors the eccentricities between a wall and the one underneath, were calculated.

The permitted eccentricity was: ± 5 mm
Of the observed eccentricities were: 40% less than 5 mm (See histogram in fig 5)
60% exceeded the PD

Comments on § 7.23
This 60% is rather large and unsatisfactory. Imperfections like this, can involve the risk of jeopardizing the safety of constructions, especially those which are less robust than the one in this study. The result could have been better, if the interaction between the three PD's has been changed, because ± 20 mm for position and ± 12 mm for verticality against only ± 5 mm for eccentricity is not very realistic. The contractor in his turn could, when setting out the walls, have taken a feedback to the wall below, e.g. through a
6.5 Presentation of accuracy data

With the program SPSS-graphic, accuracy data can be graphically presented in different ways, e.g., histograms, circle diagrams, contour lines.

7 ACCURACY DATA

7.1 Primary net

Primary nets are usually connected to official nets, and according to the recommendation in ISO 4463, by only one connecting point and direction. By doing so, inaccuracies in the official net will be eliminated. The standard specifies acceptance criteria for the accuracy of primary nets. The one applied on this site concerns: "When distances and angles, derived from given coordinates (here by the consulting firm), have to be compared to those determined by a compliance measurement*.

Example:

Distance calculated from the coordinates: 31,356 (PP 54-56)
Compliance measured distance: 31,365
Deviation: 7 mm

Permissible deviation: \(2 \sqrt{L} (1.5 \sqrt{L})\)

Angles calculated from the coordinates: 145.342 gon (PP 56-65-9)
Compliance measured angle: 145.527 gon
Deviation: 0.176 gon

Permissible deviation: \(\frac{20 \sqrt{L}}{\sqrt{L}}\)

* L = the shorter of the two distances, defining the angle

\(x\): According to the draft proposal of ISO 4463 revised.

Comments on § 7.1

ISO 4463 recommends that the establishment of primary nets has to be planned in good time. This is a normal accuracy precaution in quality control. This is of not done because: "good time" is seldom available on sites, or it has not been thought of, or for competition reasons found to cost too much. Neglecting the recommendation can become expensive. Figure 1 - as an example - shows some very acute angles of intersection, which could even have been detected by just a "quick look" at the site plan and corrected accordingly. This accident caused an inaccuracy of about 30 mm, but as a piece of good luck located in the resection direction, used in the setting out, instead of perpendicular to it, thus reducing the risk of serious setting out errors.

The accuracies of the other distances and angles fulfilled the criteria in ISO 4463 very well.

7.2 Bearing walls (thickness 160 mm)

7.2.1 Position deviations

The histogram in figure 3 shows the distribution of the position deviations of the finished walls, measured on a 2x1.5 metre spaced grid. The deviations are due to those in setting out and shuttering, but also to deformations of the formwork which occurred during concreting.

The permitted position deviation was ± 20 mm.

Of the observed deviations were: 99% less than 20 mm, 1% exceeded the PD by 1 mm

82% less than 10 mm

The sector diagram in figure 4 presents the proportion of setting out, shuttering and deformations on the final result. This information could be achieved by measuring in the positions points for the formwork, set out by the contractor, the formwork itself and finally the walls after striking the formwork.

Figure 3. Walls, position deviations in the position deviation of the walls

Figure 4. Proportion of setting out (I) shuttering (II) and formwork deformations (III) in the position deviation of the walls

7.2.2 Verticality deviations (= a part of the shuttering deviations)

Since the measuring values from the grid points were expressed in A, B and C coordinates, the computer could easily calculate the verticality deviations.

The permitted verticality deviation was ± 12 mm

Of the observed deviations were: 98% less than 12 mm, 3% exceeded the PD by 2 mm

80% less than 5 mm.

Comments on § 7.21 and 7.22

The accuracy reported above can be considered as normally achievable.

7.2.3 Eccentricity

With the aid of the A, B and C coordinates obtained on the different floors the eccentricities between a wall and the one underneath, were calculated.

The permitted eccentricity was: ± 5 mm

Of the observed eccentricities were: 40% less than 5 mm (See histogram in fig 5) 60% exceeded the PD

Comments on § 7.23

This 60% is rather large and unsatisfactory. Imperfections like this can involve the risk of jeopardizing the safety of constructions, especially those which are less robust than the one in this study. The result could have been better, if the interaction between the three PD's had been changed, because ± 20 mm for position and ± 12 mm for verticality against only ± 5 mm for eccentricity is not very realistic. The contractor in his turn could, when setting out the walls, have taken a feedback to the wall below, e.g. through a
boxed out opening in the floor, instead of just a "Floor by floor setting out". Hence: Both designer and contractor seem to have overlooked the risk of missing the aim. Failures of this kind are however not unusual in building and the cause is "The communication error". This is a fact which has been known for many years. No wonder that one can still hear the old question: "When will designers and contractors learn to talk to each other?"

Figure 5. Eccentricities between walls on different floors

7.3 Beams and floor slabs

7.3.1 Deviation from specified formwork level.

Position points in level were not set out, but the heighting was done by lowering, raising or propping up the bearing shorings underneath the bottoms, until the proper level was reached. The accuracy of this combined levelling/shuttering procedure was investigated by levelling a grid with a 2 metre spacing on the bottom of the formwork on all floors. 400 points were levelled.

The permitted level deviation was: ± 20 mm
Of the observed level deviations were:
   100 % less than 20 mm
   96 % less than 10 mm

Comments on §7.31

These accuracies fulfilled the PD by a wide margin. However the proportion between "Too low" and "Too high", within the PD, was 45 % against 55 %. This 45 % brought about some consequences, as can be seen below.

7.3.2 Deviation from specified slab level.

When pouring the concrete a rotating building laser was used to control the proper level of the surfaces, so called free hand pouring. After hardening and striking the formwork, the surfaces and soffits were levelled on the above mentioned grid points.

The permitted level deviation was: ± 20 mm
Of the observed surface level deviations were:
   100 % less than 20 mm
   93 % less than 10 mm
Of the observed soffit level deviations were:
   95 % less than 20 mm
   50 % less than 10 mm
   5 % larger than 20 mm

The 5 % too large (between -20 and -25 mm) were all located on the same floor.

Comments on §7.32

Due to settlements of the formwork during the pouring, the soffit values differ from those in §7.31. Such settlements usually occur, but by bad luck the values exceeding the PD by 5 %, were those of the soffits cast into the formwork having the 45 % "Too low" levels within the PD. (See §7.31.) The settlements on the floors with the 55 % "Too high" levels did not follow the same trend beyond the accuracy limits. This means that when shuttering for floor slabs, it should preferably be made of PD values rather than +PD values.

The consequence of this settlement were: Increased slab thickness, reduced room heights.

7.3.3 Deviations from specified slab thickness (260 mm)

Using the measured level of corresponding grid points on surfaces and soffits, the computer calculated the slab thicknesses on the four floors.

The permitted thickness deviation was ± 12 mm
Of the observed slab thickness deviations were:
   51 % less than 12 mm
   28 % less than 5 mm
   49 % larger than 12 mm

The 49 % too thick (between 12 and 32 mm) were located on the floor mentioned in §7.32.

Comments on §7.33

The fact that the slab is too thick is not only caused by the settlement of the formwork as such, but in a way also a consequence of "Free hand pouring", because the laser reference plane is fixed over the surface and does therefore not follow the formwork during the pouring. It only indicates when the proper level has been reached. It does not control the thickness of the slab. This is disadvantage of this method which otherwise is time saving. Floating the concrete in the conventional way along levelled guide shutters, placed on the reinforcement, usually reduces the risk of getting too thick slabs and consequently of applying extra loads on the bearing parts of the structure. (See also comments on §7.32.)

7.3.4 Deviations from specified room heights

There was no permitted deviation from room height specified on this site, but the normal one given in the Swedish AM was ± 20 mm. The accuracy of 304 room heights were investigated.

Of the observed room height deviations were:
   83 % less than 20 mm (+PD in AM)
   49 % less than 10 mm
   17 % larger than 20 mm

This 17 % refers to room heights which are between 20 and 31 mm too low, all of them on the said floor.

Comments on §7.34

Due to this imperfection, a number of partition walls panels and vertical frame studs had to be adjusted for actual height, involving time-consuming measuring of available heights and, cutting panels and studs accordingly. (See also comments on §7.32.)

7.4 Flatness of floors

The surfaces of the slabs were final-screeded with a superplastifier. Flatness tolerances for this procedure were - as usually - specified by PD's for slope,
e.g. 5 mm/m and curvature, e.g. 3 mm/m. The accuracy was investigated by levelling a grid with a 1 meter spacing.

All the observed slope and curvature deviations were less than the PD’s.

Comments on § 7.4

On sites the connecting compliance measurements are traditionally often done with straight edges and additional measuring tools, and ergonomically it is not very appealing. It implies crawling over floors with the temptation to give up before long, leaving the greater part of the floor untested. An efficient and fast measuring procedure is grid levelling and then reporting the result by means of contour lines (figure 6).

Figure 6. Graphical representation of flatness of floors by means of contour lines, at intervals of 1 mm

Contour lines give a good direct view of the overall flatness of the floor, and easily show where a detailed inspection with a straight edge should be done, it reduces the crawling to a minimum.

8 DEFORMATIONS MEASUREMENTS

The deformation measurements concern mainly the deflections of beams, 10 m long, (600 x 390 mm). They began during construction and will continue several years ahead. Deflections were determined by levelling 5 measuring points, 2 at each end of the soffit of the beams and the other 3 equally divided over the remaining length. The points consist of a ring on a shaft, fixed anchor with a wedge in the concrete. The measuring marks are the edged insides of the ring allowing a well defined constrained centring of the invar levelling staves when suspending them on the insides. The precision levelling instrument, which is used is an N-3 with which the values on the staves can be read of to 0.01 mm, a value which is generally not equal to measuring accuracies or precisions. As, a measure for accuracy, the result from repeated levelling was used, which showed discrepancies of not greater than 0.1 mm, sufficient for the purpose.

The measuring values obtained at the two ends of a beam served as reference values for the calculation of the deflection of that beam in the other three points, thus eliminating settlements.

The largest deflections which have been observed up till now are 20 mm, but only on the roof bearing beams, this being due to heavy snow loads. On the other floors they were less than 10 mm and apparently not increasing. Deformations of the roof beams seem to continue.

Straightness deformations of walls and columns will also be investigated.