pattern was used, that had been derived from the verification measurements. Fig. 4, showing the results of the calculations, also illustrates the variety of boilerplants that can be analysed with the Boilerselection-program.

Fig. 4 Boilerselection-program, results of analysis of various boilerplants. (V = cascade, O = reverse seq.; A = on-off, H = high-low, M = modulating; C = convent.eff, H = high eff.; W = weatherdep., C = constant; SK = butterfly v., "150" = 50% overcapacity).

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.

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

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KEYWORDS

limit state design, setting out, measuring-in, accuracy data (collection, calculation, presentation), positional and dimensional deviations, deformations of load bearing parts

ABSTRACT

In Sweden new regulations - applying the method of limit state design - have been introduced on a voluntary basis and will become compulsory within a few years. On a building site SIB investigated the geometrical consequences of these regulations in practice. This field study, which is the first of its kind, consists of two parts:

* Determination of deviations due to e g setting out or shuttering
* Determination of deformations of the structure as a possible result of the regulations

In both parts modern surveying techniques were applied for the collecting of a large number of accuracy data. One of them was the method of "Free station points".

The local A, B and C coordinate system on the site was chosen as the reference object for the measuring-in and the calculation of accuracy data for different items. The coordinate points were marked by elevated target points in the primary net work around the site.

The advantage of using coordinate systems as reference in this kind of research is, that from observed positional deviations other deviations, e g from verticality, thickness, eccentricity, slope, straightness of flatness, can easily be derived by the computer.

After storage of the data in the computer, statistical parametres were calculated. The results were graphically presented in different ways: histograms, circle diagrams or contour lines giving a direct view over the degree of the flatness of e g a floor slab. The study does thus also give information about alternative uses for the computer in collecting accuracy data.

It is expected that the application of the new regulations will require more attention to accuracy than at present. The paper therefore contains examples of some interesting accuracies and comments e g on how these accuracies can easily be improved. Improvements do not necessarily require the use of the latest innovations in measuring - or production technique, more important simply is a better communication between office and site.

Techniques modernes en matière de métrage et de calcul par ordinateur à la recherche, au calcul et à la présentation des données précises d'une construction concue 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 à 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 étudié sur un chantier, les conséguences 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 dûs par ex à l'implantation ou au coffrage
- Détermination des déformations de la 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 métrage 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 la calcul de valeurs précises dans les différents cas. Les différents points des coordonnées étaient matérialisés par des voyants dressés dans le canevas principal 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.

Aprés 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'attend à ce que l'application de la nouvelle règlementation exige davantage de précision qu'à l'heure actuelle. Le présent document contien 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 mesurage 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, Åke 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 hesitance, 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:
The primary one was:

* 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 REFRENCE 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 postions, 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** coordintes, 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.

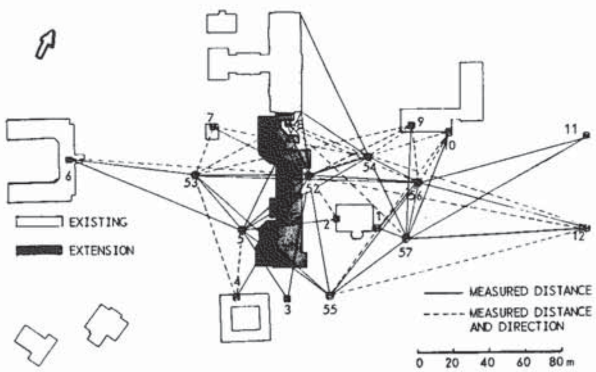

Figure 1. The building project and the primary net on the site

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 refence 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. Then the short offset distances between the sighting axis and selected points on the structure were measured in with a rod (figure 2). Investigations on the Mårtsbo test field showed that a measuring accuracy of S = 1.3 mm can be achieved.

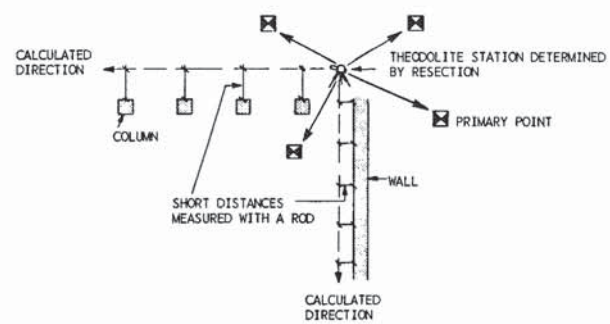

Figure 2. The principles of the collection of accuracy data with the method of free station points. In this diagram the measuring-in of the position of the bearing walls.

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 SPSSX the statistical parametres were taken out.

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 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:	7 mm	
Permissible deviation: $2\sqrt{L}$ $(1.5\sqrt{L})^x$	11 mm	(8 mm) L in metres
Angles calculated from the coordinates:	145.1342 gon	(PP 56-55-9)
Compliance measured angle:	145.1237	
Deviation:	0.0105 gon	
Permissible deviation: $\frac{0.15}{\sqrt{L}}$ $\frac{(0.10)^x}{\sqrt{L}}$	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 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)

7.21 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 occured 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.

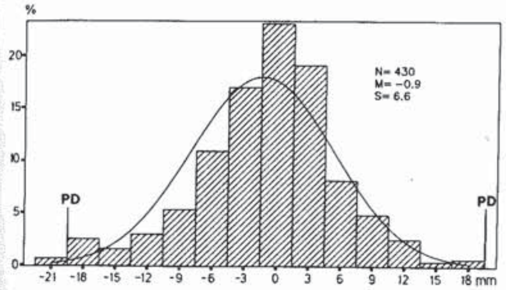

Figure 3. Walls, position deviations

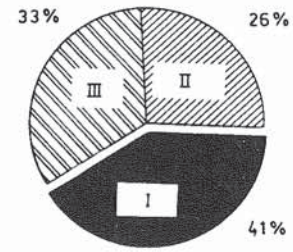

Figure 4. Proportion of setting out (I) shuttering (II) and formwork deformations (III) in the position deviation of the walls

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. 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.

7.23 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 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

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

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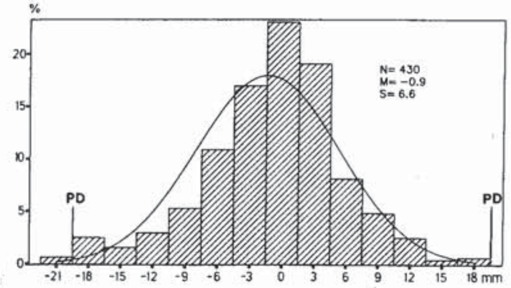

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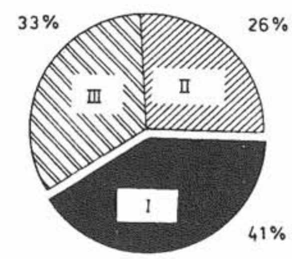

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Since the measuring values from the grid points were expressed in **A, B** and **C** coordinates, the computer could easily calculate the verticality deviations.

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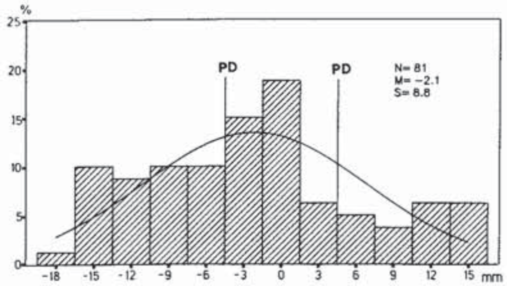
With the aid of the **A, B** and **C** coordinates obtained on the different floors the eccentricities between a wall and the one underneath, were calculated.

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".



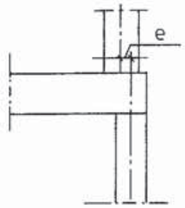


Figure 5. Eccentricities between walls on different floors

7.3 Beams and floor slabs

7.31 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
and: 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.

7.32 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
and: 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 heigh" levels did not lower the soffits beyond the accuracy limits. This means that when shuttering for floor slabs, use should preferably been made of + PD values rather than - PD values.

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

7.33 Deviations from specified slab thickness (260 mm)

Using the measured levels 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 settlements of the formwork bottom during the pouring. It only indicates when the proper level has been reached. It does not control the thickness of the slab. This is a 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.)

7.34 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 AMA is ± 20 mm. The accuracy of 304 room heights were investigated.

Of the observed room height deviations were: 83 % less than 20 mm (= PD in AMA)
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 wall 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 curavture, 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 uninspected. An efficient and fast measuring procedure is grid levelling and then reporting the result by means of contour lines (figure 6).

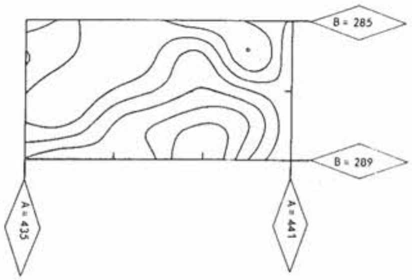


Figure 6. Graphical representation of flatness of floors by means of contour lines, at intervals of 1 mm

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 invarlevelling 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.

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