PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Geodetic Aspects concerning Possible Subsidence in Southeastern England

J. Kelsey

Phil. Trans. R. Soc. Lond. A 1972 **272**, 141-149
doi: 10.1098/rsta.1972.0040

Phil. Trans. R. Soc. Lond. A. **272**, 141–149 (1972) [141]
Printed in Great Britain

Geodetic aspects concerning possible subsidence in southeastern England

By J. Kelsey
Ordnance Survey, Romsey Road, Maybush, Southampton

The various geodetic levellings carried out by the Ordnance Survey are reviewed briefly and the evidence of land movement in Great Britain shown by the results of these levellings is considered.

Current lower order levelling in southeast England is compared with levelling carried out before 1939 described by Longfield (1932) and Lloyd (1831).

Attention is drawn to the existence of deep bench marks in London. Consideration is given to the action that is needed to ensure that the relative movements of land and sea can be suitably monitored in the future.

Introduction

As the national survey organization of Great Britain, the Ordnance Survey maintains a network of geodetic or precise levelling covering the country; this network serves two main functions:

(*a*) To provide a comprehensive vertical reference system related to mean sea level for constructional and mapping purposes.

(*b*) To provide basic scientific data for research into crustal movements and long term variations in relative elevations of the land and the sea.

In considering the geodetic aspects of the relative movement of land and sea in southeastern England, it is first necessary to study the evidence over the country as a whole. Two factors have seriously inhibited the Ordnance Survey in this study. First, comprehensive records of most levelling done before 1939 were destroyed by enemy action in the last war. Secondly, the data on mean sea level from tide gauges is seriously lacking as regards reliability, continuity and geographic distribution. The position is now improving as new gauges are installed and regular checks on maintenance at selected gauges are made; but it will still be some years before adequate and comprehensive information is available.

First geodetic levelling

The first geodetic levelling of Great Britain was carried out during the period 1840–60 to the accepted standards of the time (figure 1) and is fully described by Jolly & Wolff (1922). The datum was mean sea level at Liverpool derived from observations over a 10-day period in March 1844 and the inadequacy of this to determine a reliable datum is evident. This levelling sufficed to control the contouring for mapping completed in the latter part of the last century; but the inaccuracies of the levelling and the datum became apparent by comparison with tidal information around the coast, and by 1911 it was decided to carry out a second geodetic levelling. Any comparison of the results of this first geodetic levelling with subsequent levellings is clearly of little scientific significance.

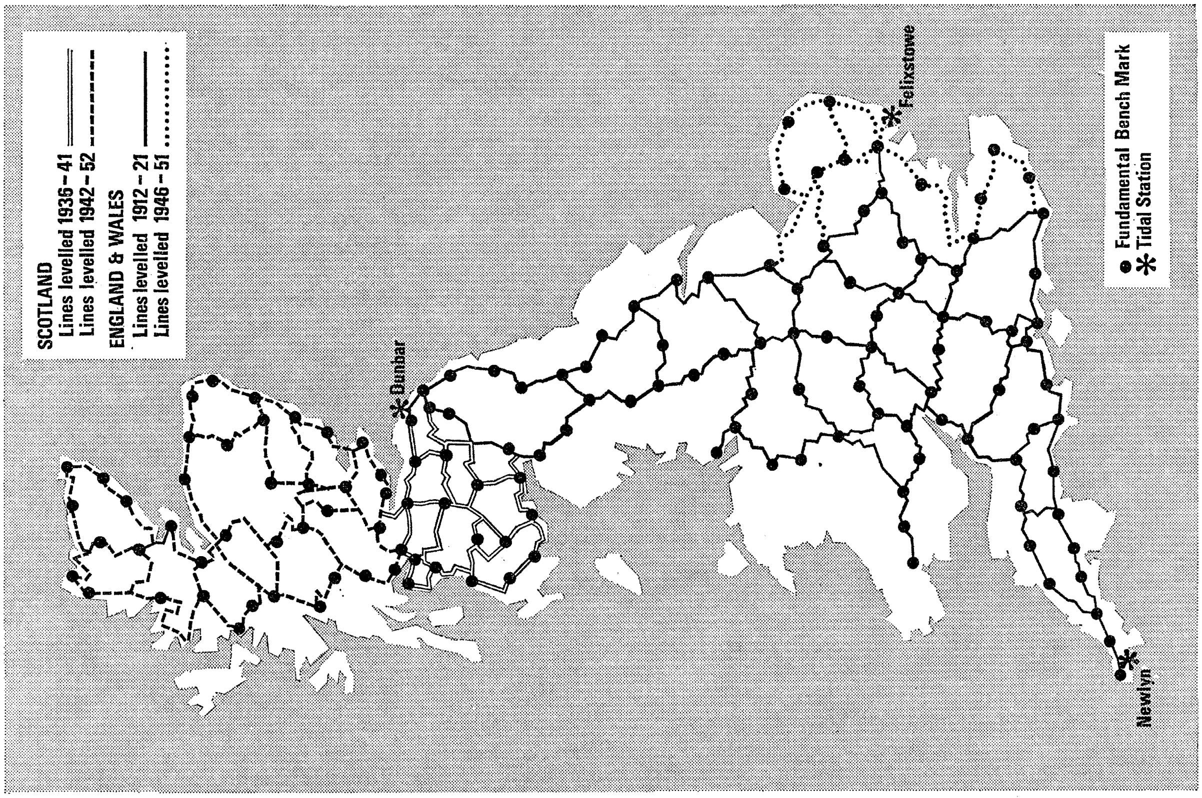

FIGURE 2. Second geodetic levelling, 1912–21 and 1936–52.

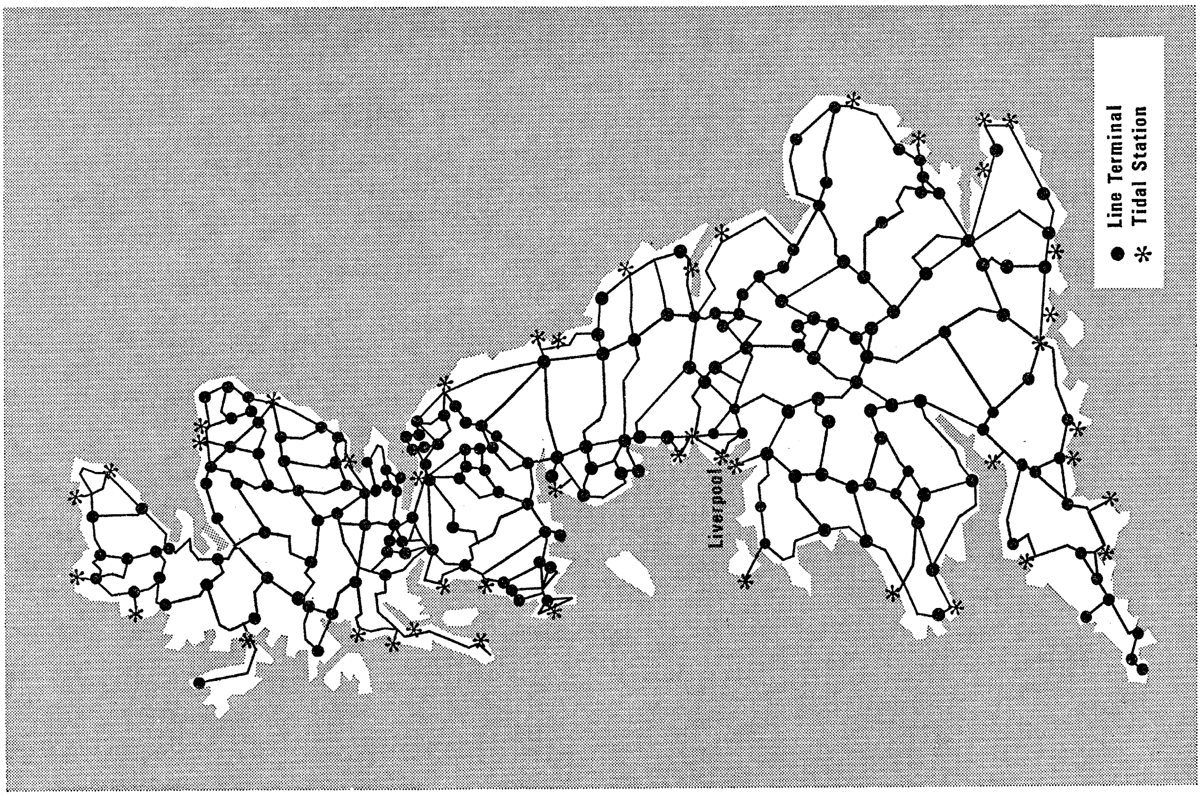

FIGURE 1. First level network, 1840–60.

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Second geodetic levelling

The second geodetic levelling of England and Wales was observed between 1912 and 1921 (figure 2). The network was not extended to Scotland until 1936–52. The instruments and techniques used compare favourably with modern standards. To determine a reliable datum

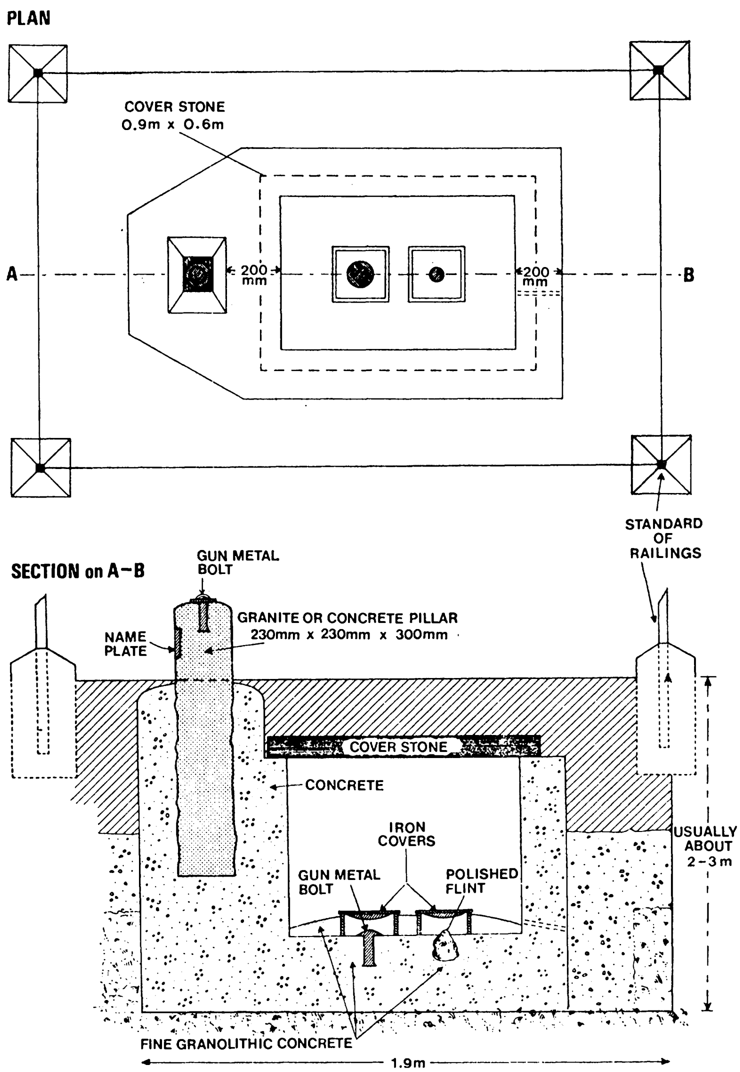

Figure 3. Fundamental bench mark. Sites are specially selected with reference to the geological structure, so that they may be placed on sound strata clear of areas liable to subsidence. They are established along the geodetic lines of levels throughout Great Britain at approximately 50 km intervals. They have three reference points, two of which, a gun metal bolt and a flint are contained in a buried chamber. The third point is a gun metal bolt set in the top of a pillar projecting about 30 cm above ground level. The pillar bolt is the reference point for general usage.

tidal observatories were set up at Dunbar in 1913, at Newlyn in 1915, and Felixstowe in 1917. Values of mean sea level at each gauge, derived from data up to 1921 were related via the levelling, and mean sea level at Felixstowe appeared to be 10 mm below that at Newlyn and at Dunbar 250 mm above Newlyn. No satisfactory explanation existed for this slope in mean sea level and as this difference in mean sea level at Dunbar and Newlyn of 250 mm was considered to be greater than the likely error in the levelling connexion, the datum surface selected for the levelling was the mean sea level at Newlyn between 1915 and 1921.

Fundamental bench marks (figure 3) were established at about 50 km intervals throughout the country in areas and sites considered to be geologically stable, to form the basis of the primary network and for future scientific research into crustal movement. The network avoided areas thought to be geologically unstable, and therefore was not extended to the coasts of southeast England.

Third geodetic levelling

The third geodetic levelling of England, Scotland and Wales was observed between 1951 and 1959, using instruments and techniques similar to those of the second levelling (figure 4). Wherever possible the same levelling lines were followed, but additional lines were added to strengthen the network, to provide better control for lower order levelling all over the country and to facilitate the connexion of tide gauges to the network. All the old fundamental bench marks were included and a number of new ones added. The same datum was used as for the second geodetic levelling.

Comparison between second and third geodetic levellings

The accuracy of geodetic levellings is assessed by circuit misclosures using formulae of the International Association of Geodesy (1950) and the total probable error of each levelling is

second geodetic	1.8 mm$\sqrt{\text{km}}$
third geodetic	1.2 mm$\sqrt{\text{km}}$.

Both levellings are within the tolerance of 2 mm$\sqrt{\text{km}}$ which is the criterion used to define first-order networks, and the third is somewhat more accurate than the second. Both compare reasonably with similar networks in other countries.

The comparison of altitudes at fundamental bench marks derived from the two levellings (figure 5) suggest that, while there are small changes in elevation of the land in southern and central England relative to Newlyn, these are not significant compared with possible errors in the levelling; but in northern England there is an apparent uplift of the land relative to Newlyn of 175 mm in the 32 years between the levellings (or approximately 5 mm per year). This is significant. While land uplifts of this order and greater due to deglaciation have been recorded in northern Scandinavia, this figure for Great Britain cannot be accepted without supporting evidence from some other source such as oceanographic data.

Here one meets difficulty owing to the lack of reliable tidal records. For example, of the three tidal gauges originally set up by the Ordnance Survey, only at Newlyn are there continuous reliable records. However, Rossiter (1967) published an analysis of data from tide gauges in Northern Europe where records for 30 years or more were available before 1950 in an attempt to correct mean sea-level values for atmospheric effects. Relating his values for mean sea level at Dunbar and Newlyn derived from the third geodetic levelling, mean sea level at Dunbar was 290 mm higher than that at Newlyn. By considering data over northern Europe, Rossiter deduced that slopes in the mean sea-level surface existed, which could be attributed to oceanographic causes and which varied in magnitude and size. In addition, it is significant that Levallois

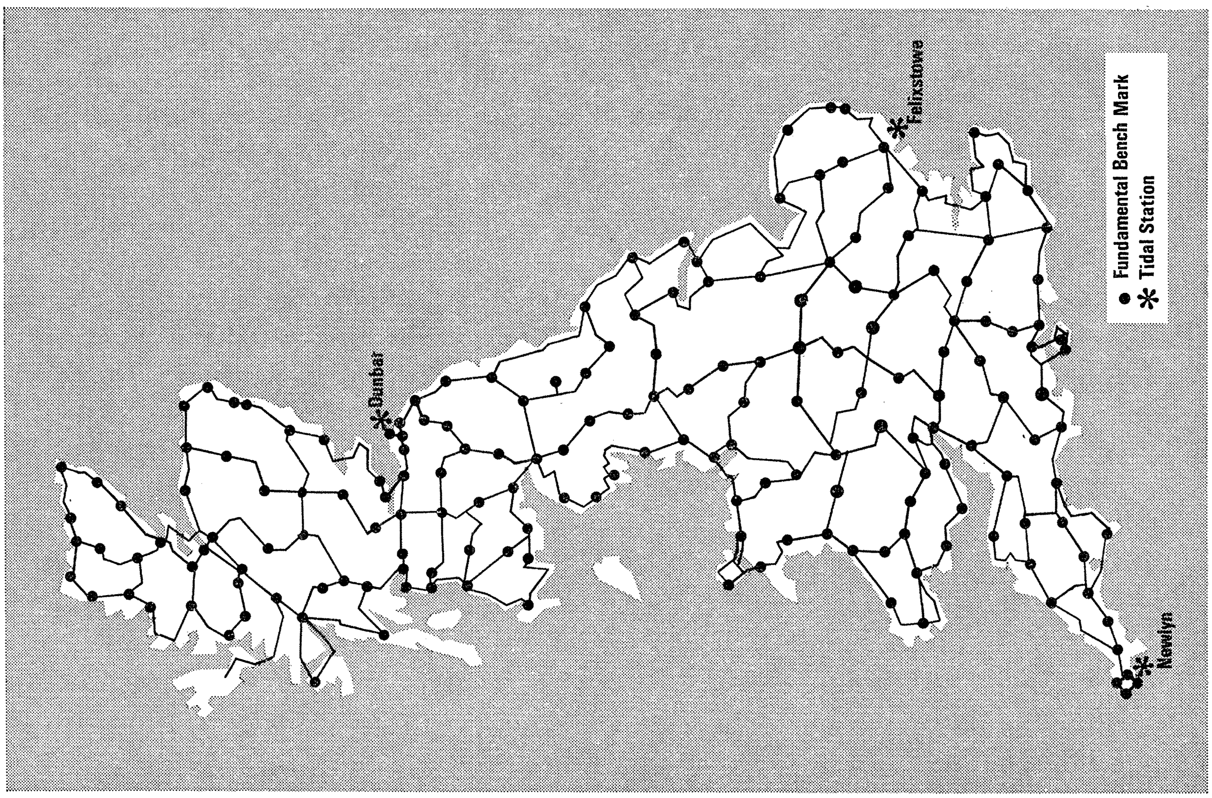

FIGURE 4. Third geodetic levelling, 1951–9.

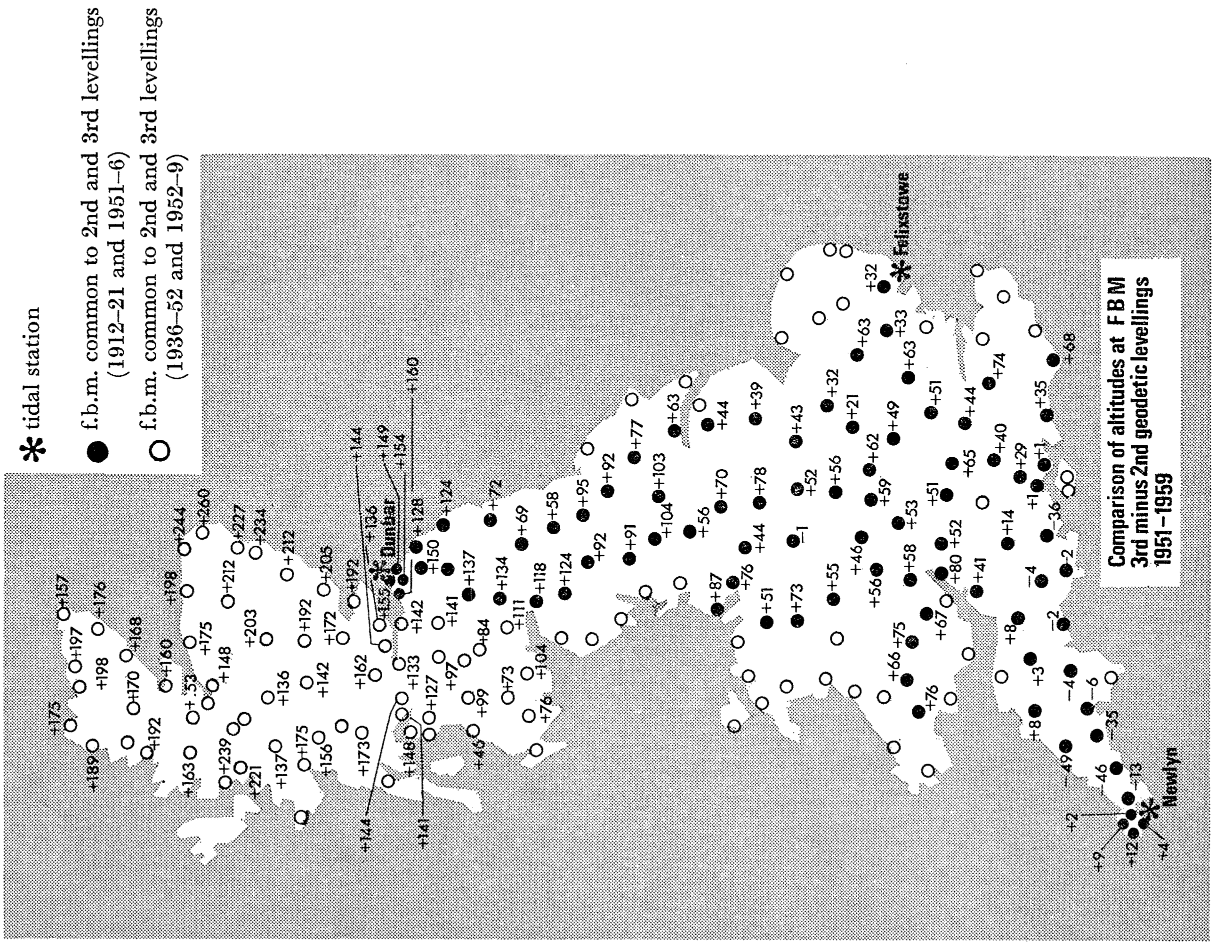

FIGURE 5. Comparison of altitudes at fundamental bench marks: third minus second geodetic levellings 1951–9 in mm.

& Maillard (1970) had deduced from the recent geodetic levelling of France that there is a rise of about 300 mm between mean sea level 1950 at Marseilles and Brest; but once again the tidal data is not reliable.

Levelling data in southeast England

Turning now to the specific problem of southeast England, little information can be gained from the comparison between the two levellings, due to the fact that the second geodetic levelling did not extend to southeast England or East Anglia. A study has been made of lower order levelling in the area and the only available data from levelling before 1939 was contained in papers by Lloyd (1831) and Longfield (1932). A number of bench marks referred to in these papers were identified and connected to a line of the third geodetic network levelled in 1953. Uncertainties over point identification and considerations of the inaccuracies in the early levellings reduce the validity of comparison with later levelling. Nevertheless, it may be of interest to record the outcome of this study.

In 1829 Lloyd, at the suggestion of the Royal Society, levelled between Sheerness and London 'to ascertain the difference, if any, between the level of the water at certain parts of the River Thames, and the mean level of the sea near Sheerness, as well as the height of different intermediate points above the sea...'. As was only to be expected, many of his marks no longer exist and it was only possible to identify four of his points, two at Sheerness, one at the Royal Greenwich Observatory and one at St Katherine's Docks. Of these four points two have been moved but records give some indication of the height differences caused by the moves. The resulting comparison between the levellings suggests that the difference in height between the marks in Sheerness and St Katherine's Docks has increased by 70 mm between 1829 and 1953. No conclusion can be reached from this, except to note the relative agreement between the levellings and the difficulty in preventing bench marks from being moved or destroyed!

Longfield also analysed the results of levelling lines radiating from a mark on the British Museum to a number of points outside London. These lines had been levelled at various times between 1865 and 1932. From these comparisons he produced evidence of local subsidence in limited areas of central London and demonstrated that such subsidence could be attributed to geological causes. The importance of this paper is not the evidence of local subsidence which has been well monitored in parts of central London, e.g. St Paul's Cathedral, but that it contains descriptions and altitudes of the bench marks used in his study and an attempt has been made to obtain heights based on the latest levelling for those of Longfield's marks which still exist.

Eleven such points fall on or near a line of the third geodetic levelling running from Croydon through the centre of London to Buntingford, Herts. Values from second-order levellings done in 1932 and 1953 have been compared with the geodetic values of 1962. In all but one case the geodetic values are lower (figure 6). The differences in height between the levellings are of the order one would expect from second-order levelling, but it is perhaps significant that in all but one case successive levellings give lower values when related to the fundamental bench marks at Croydon and Buntingford.

Thus it must be concluded that, from all available levelling data, there is no evidence of any significant change in level of the land in southeast England relative to the datum at Newlyn in southwest England. Tidal data does, however, produce evidence of variations in the relative levels of land and mean sea level in southern England. It must also be concluded that unless special precautions are taken to preserve both the bench marks and records of successive levellings in areas where subsidence is expected, no reliable data will ever become available for studies into subsidence.

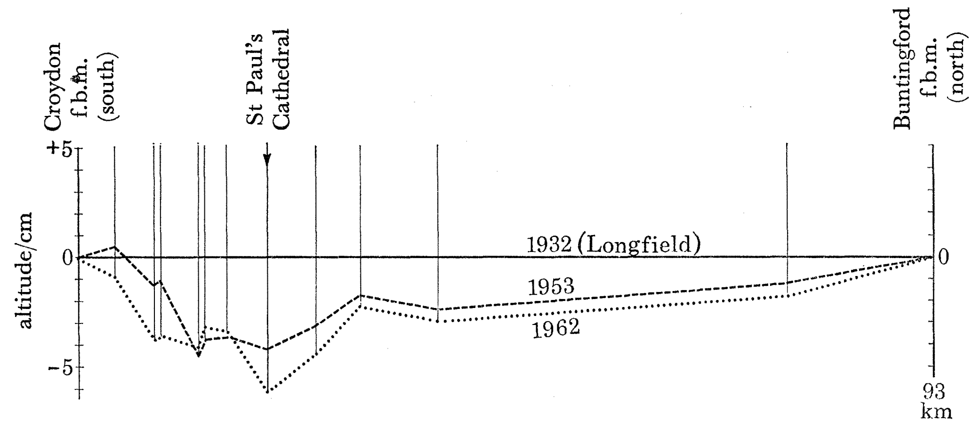

FIGURE 6. Croydon to Buntingford geodetic levelling line. Graph showing differences in adjusted altitude for those points common to Longfield's and subsequent levellings with Longfield's values taken as datum.

DEEP BENCH MARKS

In recent years, since the erection of high structures with deep foundations in central London, a number of so-called 'deep bench marks' have been installed. These bench marks vary in design but they all follow the principle of mounting in the bedrock a column which is isolated from the less stable upper strata. The length of the column can be monitored by lowering thermometers to record variations in temperature. A typical design is the one at the Shell Centre (figure 7). Other deep bench marks have been erected at London Bridge, Imperial College, and in the Barbican. To date only the Shell and London Bridge deep bench marks have been connected to the geodetic levelling.

The point of mentioning these deep bench marks in the context of this paper is to draw attention to them. So far, they have not been used to monitor subsidence in the long term but it seems possible that they afford a means of doing so in the future, provided their stability can be determined. What geological conditions need to be satisfied to ensure their stability and what sort of distribution is required to enable subsidence to be monitored over southeast England?

THOUGHTS ON FUTURE REQUIREMENTS

From what has been said so far, it is clear that much work needs to be done if the relative movements of land and sea are to be monitored. It is evident that this information cannot be obtained as a by-product of work carried out for other purposes; a deliberate long-term plan must be made once the requirement has been established. Furthermore, the plan must be coordinated as it is a waste of time and effort to monitor the land levels accurately if it is not suitably linked to comparable monitoring of mean sea level.

It seems probable that modern geodetic levelling techniques are suitable for monitoring the relative land levels, albeit there is obviously the need to consider the siting and stability of suitable fundamental bench marks. The current Ordnance Survey framework of fundamental bench marks, with possibly the inclusion of a number of strategically sited deep bench marks

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would seem to provide the basis of a framework over the country. Areas of the country of particular national concern, as for example London, may well need separate treatment within the broad overall requirement.

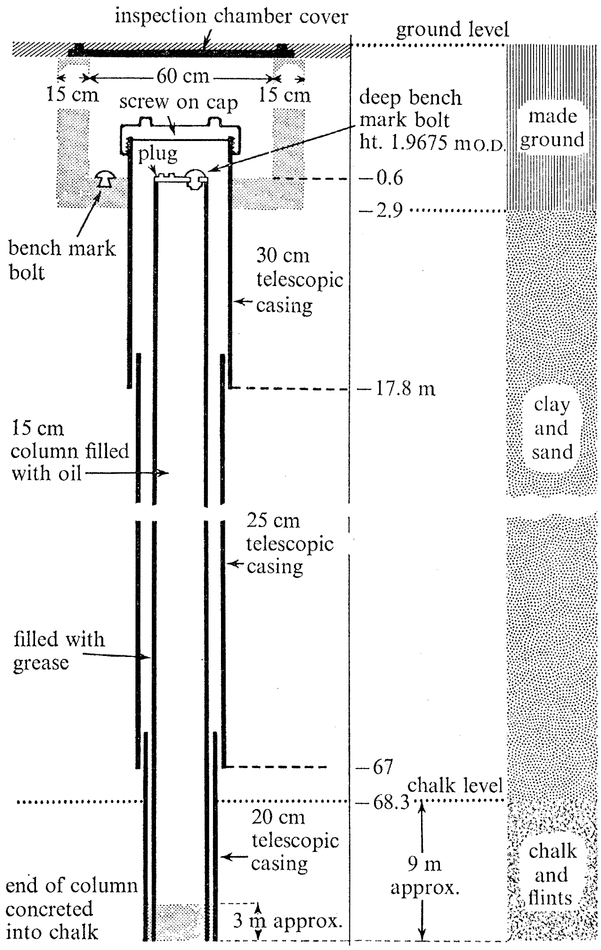

FIGURE 7. Deep bench mark.

The International Association of Geodesy (Resolution No. 14 in 1967) recommended that geodetic levelling should be carried out whenever the levelling is more than 25 years old. The results obtained from the successive British Geodetic levellings indicate that repeated levellings at such intervals are capable of contributing to the overall study of the land- and sea-level movement.

In localized areas, such as London, there may be a case for having more frequent limited geodetic levellings, say every 5 or 10 years, but these must be linked to the overall framework to build up long-term information as well as checking stability.

CONCLUSIONS

First, while there may be evidence from geological and archaeological sources to indicate subsidence of the land in southeast England, the results of Ordnance Survey geodetic work do not detect any subsidence between 1919 and 1950. This is largely due to the limited extent in the earlier geodetic levellings that have been mentioned and the destruction of comprehensive records.

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Secondly, there is every indication that geodetic levelling is capable of making a significant contribution to studies of the relative movements of land and sea provided it is part of an overall plan which embraces the results that can be obtained by other techniques and other disciplines.

Thirdly, the value of data obtained from the continuous operation of a reliable tide gauge at Newlyn since 1915 shows clearly the need for, and the benefits that can be derived from, the existence of such tidal observations. Consideration must be given to increasing the number and widening the scope of the observations taken to include earth tides if adequate data is to be obtained on crustal movements. Without such data, scientific evidence on the need for costly engineering projects for flood protection will never be available.

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