Setting Out on Site

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34.1 Principles

'Setting out', as practised on civil engineering and building sites, is the locating of the works to be constructed, ensuring that they are dimensionally within permissible tolerances and correctly constructed. This service is essentially an aid to the labour force and must necessarily be provided in a form that is easy for them to use and understand; the information must be reliable and must be available as and when required. Errors in setting out will in most cases result in remedial works which will be expensive. Whatever lines or levels are provided should be checked to be sure of their accuracy, and they should be provided to the foreman efficiently so that he can have the necessary confidence in them.

Clause 17 of the Institution of Civil Engineers' Conditions of Contract states:

The Contractor shall be responsible for the true and proper setting out of the Works and for the correctness of the position, levels, dimensions and alignment of all parts of the Works and for the provision of all necessary instruments, appliances and labour in connection therewith. If at any time during the progress of the works any error shall appear or arise in the position, levels, dimensions or alignment of any part of the Works the Contractor, on being required so to do by the Engineer, shall, at his own expense, rectify such error to the satisfaction of the Engineer, unless such error is based on incorrect data supplied in writing by the Engineer or Engineer's representative, in which case the expense of rectifying same shall be borne by the Employer. The checking of any setting out or of any line or level by the Engineer or the Engineer's representative shall not in any way relieve the Contractor of his responsibility for the correctness thereof and the Contractor shall carefully protect and preserve all bench marks, sight rails, pegs and other things used in setting out works.

In this chapter, the initials SOE (setting-out engineer) are used to identify whoever undertakes the setting out. This function is performed by engineers, surveyors, technicians and foremen. 'The Engineer' is used to define the Client's technical representative.

Since the previous edition there has been continuing development of surveying instruments and aids. In particular there is ready availability of instruments which reduce the risk of user error and of instruments with electronic direct reading and computational facilities. The work required to be 'set out' has changed little and thus the basic principles are unaltered although complex setting out can be greatly simplified by the use of computer calculations and instruments.

34.2 Surveying instruments and their use in setting out

The usual instruments employed in setting out are a 20-s theodolite and a quick-set level. The theodolites and levels will be complete in a box containing the recommended tools for adjustments and an operating booklet, and will have an accompanying tripod. Theodolites will generally permit optical plumb-bob, triplicate book, club hammer, claw hammer, nails, centre punch, hardened steel point for scribing lines on steel or concrete, knife, spirit level, crayon, pencils and cloths. Spirit levels are now available which can give alignments other than horizontal and vertical. The setting out equipment is usually cared for by the chainman who, only after he has received careful instructions, may also take care of the instruments and their tripods they should be transported in their boxes about the site. The SOE will have a kit of setting-out equipment usually carried in a shoulder bag which is large enough to also carry and keep dry a survey book, reference book or papers, and folded drawings. The kit typically comprises a 30-m steel tape, 1-m folding rule, graduated scale, 30-m fine string line, 500-g plumb bob, triplicate book, club hammer, claw hammer, nails, centre punch, hardened steel point for scribing lines on steel or concrete, knife, spirit level, crayon, pencils and cloths. Spirit levels are now available which can give alignments other than horizontal and vertical. The setting out equipment is usually cared for by the chainman who, only after he has received careful instructions, may also take care of the instruments and will generally transport them in their boxes about the site. The chainman should be allocated to one or more SOEs and should be instructed in a signalling system which the SOE will use to indicate his requirements when out of hearing. The chainman should be instructed as to the correct method of holding a level staff and the correct use of the measuring tape. A well-instructed chairman will greatly ease the work of the SOE, whereas a poorly instructed or indifferent one will cause errors and delays. The chairman should be provided with the necessary tools and be capable of making and erecting profiles, sight rails, batter rules, and boning rods. The staff should have access to suitable timber, which may well be stored from general site use, for such purposes. After use, the materials should be recovered. The profiles and pegs should be painted to be clearly visible and identifiable.

When taping distances it is usually more accurate to measure from the 1-m mark on the tape, with the end of the tape held clear of the starting marker. The SOE should always make it clear to his chainman what starting position he requires. Allowances should be made for measuring errors which occur due to
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slackness in the tape. The catenary error between the ends of the tape can be greatly reduced by providing intermediate support. Without such support a 33-m steel tape weighing 0.0219 kg/m with a 5 kg tension will give an inaccuracy of 28.8 mm and with a 10 kg tension an inaccuracy of 7.2 mm. Likewise, correction should be made for measuring on slopes. The measurement of 33 m on a 1 in 50 slope means a 7.5 mm error on the horizontal measurement, and on a 1 in 10 slope would mean an error of 164 mm. The best method of slope correction is by taking levels at each end and calculating the correct length which is the taped length along the slope less the sum of $\frac{H^2 + H^p}{21}$, where $H$ is the difference in height.

Appropriate setting out should be completed as a closed traverse and any cumulative errors traced and eliminated by recognized surveying techniques. When closed traverses cannot be used, try to check your setting out using different reference points so that any mistakes are unlikely to be repeated. Unless it is impractical, forward and back-sight distances for levelling should be roughly equal as this will reduce inaccuracies if the instrument is in need of adjustment.

All tapes and bands should be kept clean and lightly oiled to avoid rusting, but not so oily as to pick up dirt.

The marking out of a right angle without an instrument is quickly achieved by using a 3:4:5 triangle of measurements. Rapid but more approximate results can be obtained by standing over the offset point on the baseline with arms out sideways at shoulder height in the line of the baseline. As the hands are brought together in front of one they will indicate the line at right angles. Use can also be made of optical squares.

When establishing a route across difficult country with bushes or other features obscuring required lines, it is often quicker and simpler to locate the positions of markers in clearings where they can be seen and to transfer lines locally.

When transferring a mark to concrete or steel make a mark each side of the required position and scribe a line between them with a hard steel point. On concrete this can be stencilled-in with indelible pencil and on steel the required point can be emphasized with a centre punch.

Try to identify setting-out pegs by writing on them or colour coding but first remove any previous references.

When possible, check your initial setting out using a different set of references to avoid inadvertently repeating an error.

Temporary bench marks (TBMs) are usually established on hopefully immovable features of the site. They can be scribed on to the sides of walls, on the tops of foundations or kerbs, or on to piles or bases constructed for the purpose. They must all be levelled-in from the main site bench mark and regularly checked to ensure reliability. Finished work should not be permanently damaged by marking on setting-out points. Make sure that a level staff can be held truly vertical above the level mark. Sometimes a piece of steel angle iron, perhaps 1 m long, driven into the ground will meet the requirement.

Setting out usually involves knocking in timber pegs or steel pins to mark the extremities or centrelines of the excavation or area concerned. Offcuts of steel reinforcement painted white serve well and can be re-used many times. When the setting-out lines are required more accurately and are required for several operations, then timber profiles are usually employed. Commonly, these consist of low timber rails fixed to two square timber pegs. Nails are lined in on the top to denote the required centre, building or other setting-out lines. The foremen usually extend string lines between profiles. Profiles need not necessarily be accurately at right angles to the setting-out lines but reasonable accuracy makes offsetting of the line, by the foreman, much easier. The rails are often painted and the positions of the nails referenced on them in pencil.

Profiles for levelling excavations are usually set much closer to make sighting between them that much easier.

Setting-out stations are usually square timber pegs or reinforcement steels knocked well into the ground and protected with a surround of concrete. Nails or marks locate the true line or intersection point. These points can also be scribed directly on to suitable existing concrete or other surfaces. If likely to be damaged they should be clearly marked and where necessary protected by a simple fence or guard.

In special cases it may be justifiable to erect a small rigid platform above a setting-out point on which to set up the theodolite and gain a clear view not only across the site but in some cases also down into excavations.

Setting-out work has to serve the foremen and they should be given diagrams clearly indicating how the points and levels relate to the work they have to do and they should be shown the pegs, profiles, etc. from which they will work. Interference with these must not be tolerated.

Colour coding may be necessary where a profile is used with a different length of boning rod on each side or different lengths of rod for various purposes.

A number of mistakes frequently give rise to common errors. It is easy to transfer offset dimensions from drawings to notebook to site and set out bases, etc. on the wrong side of the main setting-out lines. It is easy to give some pegs and markers in offset positions and others on-line. It is easy to set up profiles accurately but set the wrong length for the boning rods. Errors of a unit can easily occur in reading tapes and staffs. The chainman can make simple errors when erecting profiles or holding markers. Simple errors usually arise, not from calculation mistakes but from lack of attention; straightforward setting out should always be checked, as well as the apparently more complex. The SOE must always be alert to pegs and profiles which have been disturbed and may have been replaced without his knowledge.

34.4 Site survey and preparations

Before the commencement of a contract it is necessary to establish a survey of the site as it currently exists, picking up all natural features and locating the site in relation to Ordnance Survey datums, local authority building lines, kerb lines of main roads, or other features that can be regarded as permanent. A principal bench mark should be established on site and agreed as a datum with the engineer. Likewise, basic lines must be agreed for the location and orientation of the works as a whole and about which they will be set out. In cases where there is the possibility of the construction of the works having an effect on adjacent properties due to construction up to the site boundary or as a result of possible ground movements or vibration, it may be necessary to survey and record features of those properties. This may comprise the recording of levels, inclinations to vertical, positions of cracks. Supporting photographs are valuable in recording the state of such properties.

The SOE now has a basis for proceeding with the setting out. He is frequently faced with the need to set out the first stages of site construction for an immediate start and the simultaneous need to establish main setting-out lines which may have to last the length of the contract and be installed with considerable accuracy. Initial construction operations usually consist of site clearance and levelling and approximate setting-out methods can usually enable these operations to commence without delay. In some cases, the SOE may not be able to establish the principal datum lines he requires until features of the site, such as old buildings, trees, mounds, etc. have been removed. The SOE will establish his principal datum
lines in positions where they can be of use for as long as possible. Positions for the principal points should be where they can preferably remain undisturbed and free from construction operations. The ground conditions and importance of these datum lines may justify the casting of a concrete block or even a pile on which to secure a stable setting-out point. The SOE will usually find it desirable to prepare a master plan indicating his principal setting-out lines, points and his key bench marks for the site. This will relate his principal setting-out lines to the building lines, centrelines of buildings, roads and principal services required on the site. This information should be used to check the dimensions given on the engineer’s drawings and copies should be supplied to the engineer with a request that he confirms that the dimensions are as required. This will also enable the engineer to satisfy himself or herself during the progress of the work.

It is essential to check as the work is carried out, to ensure that the original setting-out pegs and lines are not disturbed when soil stripping takes place. Either long pegs can frequently be obtained by knocking in steel pins, particularly if the ground is difficult to penetrate.

For these operations a lesser degree of accuracy is needed than for the setting out of foundations and building works. The SOE should bear in mind the likelihood that positions will need to be established and re-established with speed. The initial marking out of the areas to be excavated and those to be filled will be disturbed when soil stripping takes place. Either long pegs clearly visible from earthmoving machines or smaller pegs with ranging rods to identify them should be used. Attendance will be required by the SOE to provide what is needed. As soon as it is practical to do so, lines and profiles should be established around the areas in question and batter rules set up to give guidance for the forming of slopes to cuttings and embankments. It will frequently be necessary as the work proceeds to provide additional profiles and points within the excavation or on the embankments. A typical situation is shown in Figure 34.1.

Where several levels have to be established, a colour-coding system on the pegs and profiles should be adopted and this should be carefully explained to the foreman and the machine operators and the foreman should be provided with diagrams and explanations from the triplicate book. It is important to discuss the method of setting out with the earthmoving manager or foreman so that the information is provided to suit his intended plant operations when he needs it. The cost per hour of large earthmoving and excavation plant is high and its utilization is an important factor on the cost and programme of this work which is very susceptible to adverse weather conditions. As the various levels are established, new setting-out points should be provided so that deeper individual foundations and local requirements can be quickly marked out for work to proceed without delay using bulk earthmoving equipment to the best economical advantage.

It is important at an early stage to locate the toes of batters and tops of slopes to ensure that the process of shaping and trimming is carried out quickly and easily the first time. It is better to provide a few too many pegs or batter rules than to provide too little information. It may be necessary for the SOE to attend on the excavating machines as they approach formation levels literally to level them in as they proceed using a level staff attached to the side of a scraper. Lasers giving a constant plane of reference can also be very useful by providing a visible indicator to the operator as to his working level. On motorway and aerodrome contracts in areas of intersections this attendance by the SOE often saves a lot of secondary grading.

The SOE should take into account whether the bulk excavations are to be taken straight down to formation level or left high to protect the formation until on exposure it can be blinded.

### 34.5 Setting out for excavation and grading works

For these operations a lesser degree of accuracy is needed than for the setting out of foundations and building works. The SOE should discuss with the foremen the methods to be used in the construction of the works. Foremen will require pegs, profiles, batter rules and other information in locations which will not interfere with the movement of machines, men and materials. They may require offset pegs to be provided by the SOE or may decide to make their own offset measurements. The SOE must determine not only when the setting-out pegs and lines are required for use, so that he can anticipate these times, but also the accuracy with which the information is required in relation to the purpose for which it will be used. Where considerable accuracy is required it is customary to provide timber pegs or rails and use nails for the precise position of the line. Lesser accuracy, but greater speed, can frequently be obtained by knocking in steel pins, particularly if the ground is difficult to penetrate.

Checking is all-important and, having established setting-out points and checked that they are in the right position, it is still essential to check as the work is carried out, to ensure that the original setting-out pegs and profiles have not been disturbed during the progress of the work. So, the SOE must stay in constant contact with the construction operations and provide constant services to those operations. It is wise to check that pegs and profiles should be adopted and this

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**Figure 34.1**

![Setting out for excavation and grading works](image-url)
immediately or sealed. Likewise with embankments or fill areas, allowance is usually required for consolidation and settlement. The allowances made in each case, and how the levels given correspond to finished or initial levels, should be made clear in writing to the foreman. Surfaces should be formed with self-draining falls to avoid ponding of water upon them. Where batter rules are set up on varying ground levels to give a continuous finished sloping cut or fill line these can be quickly checked by eye for alignment.

### 34.6 Trenching and pipelaying

Pipelines, culverts, service ways and the like are usually tied to specific positions and levels where they enter and leave buildings, pass under roads and intersect with each other. It is therefore wise to set out the entire length of trench between consecutive tie-in points and locate the centrelines and essential levels at all junctions, horizontal and vertical bends and manholes. The treating of several sections together in this way will reduce the possibility of errors or late alterations. Any discrepancies in the information provided can thus be identified and resolved before the laying of services commences.

When excavating a trench the machine will usually deposit the spoil for backfill on one side of the trench whilst pipes and other materials will be delivered to the other side. The foreman will usually require pegs on the centreline of the trench and a specific offset of, say, 3 m at all key positions. He will require a profile as close to the trench as possible at centres not exceeding 45 m. If these positions are likely to interfere with trench excavation or movement of labour and materials then he may require a further profile offset from the line of the trench. The profiles should be clearly labelled with the length of boning rod to be used for excavation. The length of the boning rod should be marked on it. It is not usual to mark out the width of the trench as this will be determined by the bucket of the excavating machine, which would have been selected as the most appropriate, bearing in mind the construction width required and available bucket sizes.

Within a length of pipework between manholes there may be junctions for lead-in pipes from gulleys or other items not constructed quickly and economically. It is more economic to clearly determine with the foreman the level the latter requires, and for security should be returned to the office between uses. As excavation proceeds, the trench should be checked periodically to ensure that it is being excavated to sufficient but not excessive width. With large-diameter pipes the wrong diameter can easily be used and diameters should be checked. Care should be taken that cracked or damaged pipes are not used and connections should be temporarily sealed off to maintain cleanliness. The provision of draw wires, where specified, should not be overlooked.

The SOE should be aware of the dangers associated with trench work and should be familiar with the Construction Industry Research and Information Association guide *Trenching practice*.

### 34.7 Foundations

Foundations are commonly set out by establishing a series of profiles around the excavations with the location on these profiles of specific setting-out lines notified to the foreman. Typically these may be as shown in Figure 34.2.

![Figure 34.2](image)

These profiles are usually set just above ground level with the rails horizontal but not necessarily at any particular level. Nails inserted into the rails locate the required setting-out lines and the foreman can offset these to move from, say, column centreline to the outside column face or exterior face of the brickwork to suit his requirements. He will normally stretch cord lines or piano wire between the nails and from these he can plumb-down using a spirit level or plumb bob. For level purposes he may require level profiles but more usually a series of specific level points on the works can be transferred by the foreman using straight edges and spirit levels or, more commonly on building
contracts, with a water level. Once the foreman has been provided with setting-out profiles he can usually get by with little further assistance from the SOE other than in checking the various stages of construction. In many cases it is helpful for the SOE to set up a theodolite over a setting-out point and transfer a line directly into an excavation or on to a foundation at a number of points for the operators' easier use.

Once the foundations have been correctly installed it is comparatively simple to transfer lines and levels up and through the building supports. On the other hand, inaccuracies in the foundations will be difficult to overcome with later construction, and it is necessary that key items such as holding-down bolts for steel frames, reinforcement starter bars for in situ concrete construction and pockets for precast concrete columns are correctly positioned and levelled. The SOE should consider at an early stage the tolerances which are appropriate in comparison with the cost of remedying any inaccuracies later. The SOE must be aware of the extent by which the accuracy of the works may deviate from the positions given on the drawings. These tolerable deviations govern what is acceptable. General guidance on tolerances is contained in British Standards and in particular in BS 5066 but the contract specification may set particular requirements.

Holding-down bolts are usually assembled in a frame slung from a template. The bolts usually have the bottom head under a washer plate with a sleeve tube above to provide an annular space around the bolts after concreting. The threaded end protrudes through the template and a top nut can be adjusted to set the bolts to the required level. It is important that the bolts should hang vertically and the sleeves should provide the bolts with some play after concreting. On many occasions the washer plates are replaced with steel members joining two or more bolts and this helps correct installation. These bolt assemblies have to be supported within the proposed concrete foundation. Supports, spanning across the base excavation or shutters, are frequently used. Since they will be subject to deflections and dislocations they must be set firmly into position. Where the assembly is difficult to locate and suspend accurately, a frame should be made and supported on the concrete blinding. The supporting legs may or may not be lost in the concreting of the base but any parts above the concrete level can be re-used. This method is particularly appropriate if the bolts have to be built solidly without sleeving into the foundations.

When the bolts are sleeved they should be tapped with a hammer to make sure they are free as the concrete is setting. After concreting the threads should be cleaned, regreased and wrapped with sacking for protection and the sleeves covered to prevent stones from entering.

Starter bars protruding from bases into columns or walls usually extend one lap length above the height of a small concrete kicker. Starter bars and kickers need to be set accurately and restrained there to provide the correct concrete cover within the column or wall shutter and to lap correctly with the lower end of the column or wall main reinforcement. It is essential to check starter bars before, during and on completion of concreting. Where the kicker is cast integrally with the base it will be checked with the level and positioning of the reinforcement.

Where pockets are to be formed in the foundations for precast concrete or steel sections, they should be sized for a reasonable clearance all round so that this can finally be effectively filled with concrete using a slim poker vibrator. Such a clearance can also be useful for removing any debris from the pocket. An excessive clearance, on the other hand, can affect the size of column base and will increase the temporary wedging and guying used to position the column accurately. Again, it is important to locate the pocket accurately. The pocket framework will be subject to an uplift from the fluid concrete which must be resisted. Rather, the box should be set low as it is easier to pack up than remove concrete to deepen the pocket. The material forming the pocket should be so constructed that it can easily be removed.

Once column bases have been concreted, it is usual to scribe the centrelines each side of the column position on the concrete. This serves to check that they are correct and is very useful to the erectors of the steel or concrete framework for rapid erection.

Structural steel framework erection should almost set itself out if the columns are properly aligned and levelled on their baseplates and holding-down bolts. It is desirable to set the steelwork from the centre of any building and work outwards. This will halve any creep which might occur by fixing from one end. It should not be checked finally and the baseplates concreted in until a securely braced section of the structure has been completed to ensure correct fitting of other essential members at higher levels. The SOE should check the fitting of members, that the correct members and bolts are used and that they are installed in the manner indicated upon the drawings. The SOE should give attention to the needs for structural safety during erection and the safety of the workforce engaged upon and below it. The SOE may have the duty of ensuring that mating or other surfaces which will afterwards be inaccessible, are painted first. Before any cladding is attached to the roof or sides of the building, the trusses, purlins or other members to which such cladding is to be attached should be correctly aligned and, if necessary, temporarily braced until the cladding has been attached.

With transmission towers and similar multi-legged structures it is usually necessary to use large templates to set the starter lengths of the tower legs. The four legs of each tower are usually inclined to the vertical in two directions. The excavation for the four legs are marked out with steel pins in the usual way. The starter lengths of the tower legs are attached to the corners of a square assembly template of four trusses with cross-ties between them, and the assembly is levelled across the excavations with the legs extending down into them. After checking for level and line the excavations are concreted.

### 34.8 Work within buildings

Within a building envelope there are the two categories of activity associated with building finishes and with plant. The building finishes comprise internal walls, doors, floor surfaces, ceilings and fitting-out works. The plant is associated with building services and the operations of the building user.

For building finishes, the foreman and tradesmen require reference lines and levels to which they can refer easily. Lines and levels can be provided by marking on to floor and wall surfaces in ways which can be removed later. Rotating laser beams can provide reference planes. It is essential that the light references can be re-established quickly and accurately if they need to be removed between uses. The rotating laser reference plane has advantages by servicing many tradesmen in a large area but is of less value with a number of isolated areas each requiring levels. In such cases water levels are very easy to use for transferring level datums between rooms.

It is customary to specify the level of a floor in terms of tolerable deviations from the specified level and over any length of 3 m. When goods are to be stocked to nearly ceiling height, great accuracy is required. The SOE should consult with the foreman as to the most appropriate method of construction to achieve the specified standard and should control closely the levels of the work and consistency of the materials used.

For plant there is the need to locate the positions of plant and fixings as well as the openings required in walls and floors.
for ducts and pipes. It is important to minimize the interference of one trade with another and to ensure that holes are incorporated in walls and floors as they are built. The SOE should therefore study drawings of plant and services and try to ensure that such openings are detailed on the structural drawings for incorporation during the main floor and wall construction. It is easy with some plant drawings to mistake the orientation of plant requiring a number of plantings and fixings and some care and checking is necessary.

Where items have to be built-in or are in modular units, a check is necessary to determine whether the items will fit readily with some tolerance or whether cutting will be necessary. In the latter case, the cutting procedure should be agreed with the engineer or architect as early as possible.

### 34.9 Piles and diaphragm walls

It is customary for the main contractor to provide centrelines for each base or pile group to a specialist piling subcontractor who then locates each pile position. Before piling commences it is often necessary to provide a firm working surface (pile carpet) for the specialist plant, and agreement must be reached as to the disposal of any spoil from the piling operations. These considerations make it difficult to establish and maintain the setting-out points and it is important for the SOE to monitor and check the piling operations. The SOE must so establish setting-out lines and references that he can readily check on the pile positions. The piling subcontractor will establish each pile position and then set up casing, auger, precast pile or pile shell over that position. It is easy for this casing or preformed pile to be displaced as it penetrates the pile carpet and overburden layers which can frequently contain hard pieces. It is necessary that the SOE checks the position of the casing or pile when it has penetrated a metre or so and becomes set on its course. It may be necessary to extract, fill the void and start again if the pile is displaced outside the permitted deviation. The permissible deviation from the specified pile position is usually up to 76 mm. There is also usually a tolerance on verticality of 1 in 85 which applies to the rake of inclined piles as well. The setting out of the pile must take account of these rakes if the finished tops of the piles are located at a different level to that of the setting out at the piling carpet level.

A record log should be kept of the installation of each pile, whatever type of pile it might be. When the required depth for bored piles has been reached, a light should be lowered to the bottom to assess the alignment and the condition at the bottom of the pile, and the depth should be measured. When full depth casing is not used with tripod rigs, the boring tool can be displaced by hard inclusions in the ground so producing a 'banana-like' shape. This, if it occurs, should be reported to the engineer. With precast piles and continuous casings displacement can also occur and this can throw the alignment and top position out of tolerance and so this fact must also be reported. Displacement piles have usually to be installed to a sequence and timing in order that damage or uplift of completed piles does not occur as subsequent ones are installed. It is the duty of the SOE to see that the sequence and timing are observed and to record and report the occurrence of any disruptions of adjacent piles, buildings or services. When driven piles are installed to a specified set, the SOE should check that this is achieved and at the level expected by the engineer. Any variation should be reported as the pile may be held on a boulder or other intrusion. To be assured as to the quality of a pile it is essential to have a reliable record as to the installation process and have the pile installed correctly and the SOE must see that this happens.

Sheet piling must be started by the accurate driving of the first panel of piles. Should there be uncertainty over obstructions in the upper layers of the ground it may be wise to excavate a shallow trench and place the sheet piles in it with some backfill around them. This will steady the piles and ensure a vertical start. When driving piles through gravels, in particular, there is the risk of declutching and piles going off-line and the SOE should watch for signs of this. When driving cofferdams, the lengths of the sides should equate to the width of piles to be driven and provide working tolerances around the specified dimensions of the permanent works. The cofferdam perimeter should be completed with a number of piles at one corner undriven to ensure correct interlocking.

Diaphragm walls are formed by digging under bentonite through guide trenches. A pair of 'inverted L'-shaped reinforced concrete walls form the sides of the trench. The width of the trench is 50 to 75 mm greater than the width of the digging bucket. The trench depth of up to 18 m depends on the stability of the upper ground strata in relation to the disruption expected from the digging operation. The verticality of the wall excavation must be checked regularly. When steel reinforcement cages, steel or precast concrete members are set in the trench prior to concreting it is necessary that they are suspended freely and vertically as well as to line. The suspension points for the cages and members must be designed to enable any necessary adjustments to be made under the direction of the SOE.

### 34.10 Tall buildings and structures

The ease with which tall buildings and structures can be erected depends on the accuracy of the foundations from which they rise. The formwork needs to be set accurately horizontal so that corners and other such features will be cast truly vertical, reinforcement is aligned vertically in relation to the formwork, and fixings are provided in their correct positions. It becomes increasingly difficult to correct misaligned lift of construction work as the structure rises. For these reasons it is also important for the starter reinforcement to be set out correctly for position, cover and verticality. The larger diameters of steel reinforcing bars may not be truly straight or easy to 'push over' if a misalignment of, say, 5 mm in the cover over a 1 m lift of concrete is to be corrected over the remaining vertical lifts. Likewise in the case of falsework systems erected as two-, three-, or four-legged framed towers, it is worth the care of starting correctly so that the load is correctly distributed between the members of the tower and eccentricity from the vertical does not result in avoidable lateral reactions: 1.5 degrees out of plumb represents 25 mm in a height of 1 m and a restraining horizontal force of 2.5% of the vertical load in the member is needed. In the case of structural steel frames, provision is usually made to adjust the levels of the baseplates with packers to ensure the baseplates are correctly level before they are grouted or concreted solid after the holding-down bolts have been finally tightened. Having ensured that the initial lifts of construction rise correctly, they should receive any permanent or temporary horizontal bracing and lacing as the specified positions are attained. This lacing and bracing is needed for the lateral stability of the structure and makes erection easier if it is attached at the right time. It is frequently difficult to insert such members later than the designer intended, and can result in distortion of connections and the 'building'-in of locating forces which the structure was not designed to resist.

Tall buildings are commonly clad with storey-height panels and designed with movement joints at storey heights. It is therefore necessary to check that those storey heights are controlled and accumulations of errors do not occur such that the higher panels will not fit with the fixings or the movement joints will not perform as intended. Before construction commences a check should be made on the tolerances expected on
the cladding and other components and, hence, the deviations allowed in the construction of the work on site to which the components will be attached.

It is possible to check and control verticality in several ways. Theodolites set up at ground level can project lines up the faces of a building or structure. Autoplumb can be used through openings formed for lift wells and staircases. Laser beams can be projected upwards from ground stations or piano wires with heavy weights suspended in or around the building. The weights are usually hung in a barrel of water or oil, and the location of the suspending wires easily checked against two reference lines. It is important to ensure that the edges of the floor slabs are cast accurately to the required details so that nibs and edge fixings will perform as intended in relation to the cladding. It is important to maintain cavity widths in cavity brickwork to ensure that the ties are correctly installed.

Before slipformed concrete construction commences to silos, towers and cores of tall buildings, the platform arrangements should be checked and all the critical components aligned. Misalignment can result in the platform being urged into a distorted slide which is often difficult to correct, and if corrected, often leaves poor concrete in the affected areas. The jacking rods should be vertical and the platform horizontal. The shutters should be inclined in accordance with the design and the projecting vertical bars restrained temporarily in their correct alignment. The cover to the reinforcement must be correct.

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34.12 Tunnelling

Working underground is restricting to the SOE since access to the works for surveying is generally limited. Usually, surveying is undertaken outside normal working hours which may mean only on Saturday night and Sunday along with maintenance operations. Because the survey works can be checked only infrequently, they must be reliable and firmly established. The most common underground works are tunnels and shafts and often the only access to the former is by the latter and this might involve projecting a long tunnel from a 6-m diameter shaft and consequently something less than a 6-m baseline.

Under these conditions, theodolites of 1-s accuracy are necessary and much patience is required. It may be necessary for a number of engineers to undertake the setting-out procedure several times and the mean of their lines used. It may mean that the shafts will have to be watched in case they are moving – in soft ground conditions they can lean towards large adjacent excavations as the surrounding ground readjusts to these operations.

Where considerable accuracy must be maintained, any interference arising from traffic or other vibrations, heat and pollution hazards, and general surrounding activities needs to be minimal. So even the preliminary ground level surveying in busy areas is usually carried out under more peaceful conditions at weekends or at night. It is usual to establish, across access shafts, the centrelines of the tunnels below. These centrelines are established by means of piano wires suspended down the shafts. The piano wires are wound around screw adjusters at ground level and at their lower ends have heavy 9 to 15 kg weights in baskets of water or oil. They need to be close to the shaft linings to secure as long a baseline as possible.

At the bottom of the shafts the centrelines given by these wires has to be picked up by instruments and established on markers rigidly attached to plates in the crown of the tunnel. A number of surveying methods are employed for this purpose but probably the use of Weisbach's triangle is as reliable as any. The established centrelines is projected forward whenever the opportunity occurs. An instrument reference point can never be too near to the face, particularly if curves are being negotiated. The use of laser reference beams giving the tunnel centrelines is now common practice and is a great boon to the tunnel boss.

For negotiating tunnel curves, information is usually provided in the form of offsets at chord lengths with instrumental checks as necessary and as possible. It is important to offset on the correct side of the tunnel! Before reaching tangent points it is necessary to work out with the tunnel boss how the tunnel shield.
will be adjusted to negotiate the curve and whether it can negotiate at the radius required for the finished work. It may be necessary to enlarge the tunnel at these positions using hand methods and such possibilities should be considered from the outset so that the permanent works can, if possible, be adjusted to accommodate the construction practice. Great care is required with horizontal and vertical changes in alignment or level to ensure that the work is accurately set for the new course.

Another important feature to check with tunnels in soft ground is the amount of squat or wander. Using tunnel segments, the true diameter may easily be reduced vertically and extended horizontally. It may not be a uniform distortion and considerable difficulty may be experienced with the final tunnel lining to achieve the required finished accuracy. Measurements of the tunnel-segment diameters are kept and checked for every ring both horizontally and vertically and plotted in relation to the required tunnel centreline—the result is often termed a 'wriggle diagram'.

When the tunnel is being driven under compressed air the centreline has to be transferred through an airlock and this is done by setting up the instrument within the lock, aligning it first with the outside door open, and then after closing it and compressing the lock, opening the inner door and transferring the line ahead.

When there is access above the tunnel it may be desirable to sink a borehole ahead of the tunnel and through it pick up a check on the centreline. Special precautions will be required when tunnelling using compressed air.

Increasing use is being made of full face and pipe jacking tunnel machines which can be controlled remotely. With such machines, laser beams are used in conjunction with 'targets' on the backs of the machines. By television viewing of the target and console control of the machine hydraulics, the operator in the shaft or above it can steer the machine forward and often negotiate bends.

When reliance is placed on laser beams for alignment, it is necessary to use lasers which indicate by beam oscillation when they have been disturbed.

Larger works underground employ an extension of these methods. When tunnels have to cross or deliberately connect with other services it is wise to locate these intersection points at an early stage. Positions and levels of older services are rarely accurate and adjustments to the new works may be more readily accommodated some distance from the intersection point. The SOE may need to undertake a complicated survey to locate accurately existing services by working within them. The Health and Safety Regulations should be observed when working in or adjacent to existing underground services.

Bibliography

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