ground work to be most advisable. Map and photographic study is valuable before starting the field work. Aerial photographs can obtain the most results for the money expended in the shortest time.

The one-day session was presided over by R. D. Wilson, president, Columbia River Section, American Society of Photogrammetry, Portland.

LARGE SCALE HIGH PRECISION MAPPING BY PHOTOGRAMMETRIC METHODS

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ALTHOUGH the acceptance of photogrammetric methods for the production of medium and small scale maps has become almost universal, there are particular spheres of surveying where photogrammetry has been used very little, if at all. The limitations of photogrammetry, when applied to very large scales are well known, and even in the most developed countries, the scale of 1:1,000 has in the past been universally accepted as the limit to which aerial photogrammetry could apply; and only a very limited application has been made.

Difficulties that occur in large scale surveying from air photographs are attributable mainly to the fact that the subject is viewed from above, and therefore the likelihood of detail being screened is great. At smaller scales, for example, the screening of the ground lines of buildings by their roofs is not serious, as the difference in the plan positions is normally less than the plottable amount. At very large scales, however, the acceptance of the roof line will introduce intolerable errors. At the same time, an increase in the scale will almost certainly necessitate the plotting of a large number of small details which are not always easily identified. As the size of a feature is not necessarily an indication of its importance, very serious omissions can be made. It is understandable that doubts will be cast on the reliability of a plan produced entirely by a process which is handicapped by its viewpoint, and in which, in normal circumstances, the details cannot be seen clearly enough for them to be represented on the plan, in their true character and position.

Precision plotting instruments have already reached the stage where no shortcomings in the resulting plotting are attributable to them. In other words, present-day instruments are capable of extending the scope of photogrammetry, but are handicapped by other considerations, such as the photographic process and the precision with which specific details can be resolved, interpreted and plotted. The design and production of fully automatic plate cameras, with lenses of a very high resolving power, giving quite remarkable definition, have reduced the errors previously found in the photographic process. Nevertheless, the problem of resolution and interpretation of small features is still a formidable obstacle.

In the autumn of 1947, Hunting Aerosurveys Limited were asked by the Southern Railway Company to carry out an experimental survey at the engineering scale of 1:480 (40 ft. to 1″), with the object of finding out the value of aerial photogrammetry in railway engineering. The requirement was a plan, to this scale, of a section of line at Bournemouth, Hampshire, which included a busy provincial station and yards, plotted to an accuracy in keeping with nor-

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mal railway work. So far as we knew, there was no precedent whatsoever, and any venture would be in the nature of pioneering.

If such an undertaking is to meet with any success, every possible precaution must be taken to ensure against the introduction of any errors likely to prejudice the result, and particular methods must be evolved for the particular nature of the work. Obviously, all the conditions—photographic and photogrammetric—must be tightened and the greatest care taken in the choice of the camera and plotting instrument. There are obvious limits to the degree of enlargement permitted from photo scale to plotting scale, so that for the satisfactory production of such a large scale as 1:480, the flying height must be at a minimum, while still ensuring adequate overlap and absence of ground movement. As there is inevitably a high photo/plotting scale-ratio in all work at large scale, it is all the more essential that the negative base be absolutely stable. Negatives on the normal film base will be suspect, and although in good conditions topobase film may be stable, the danger of distortion is ever present, and glass is the only base that can be relied upon entirely.

Fortunately, a plate camera (f.1. 165 mm.) was available for this experiment and although it was not of the latest type, being manually operated, it was suitable for work of a local nature of this kind. It was calculated that photographs from an altitude of 1,600 ft. would enable a satisfactory instrument set-up to be made. The Wild A.5 Autograph was chosen as being the instrument most likely to maintain the necessary precision.

The vision in this type of instrument is "sharp-sighted," and its operation is controlled by hand-wheels, two factors quite important in the type of work under review. The sharp-sightedness allows a maximum precision in orientation and also ensures that the details, so important in surveys such as these, are seen in stereoscopic form, with the maximum of brightness and definition. The hand-wheel operation and co-ordinate system are ideally suited to this high-precision plotting, allowing perfect control at all times, while the plotting table is large enough to accommodate the working sheet in such a way that the plotting is direct and absolute. No transfer or photographic process could be introduced without impairing the accuracy. Again, in the A.5, the operator views his model at a larger scale than it is being represented on the plan, so that minor deviations at the observing end will be reduced.

With the plate-camera/A.5 combination, the possibility of a satisfactory result was high, provided the difficulties of screening and interpretation could be at least partly overcome. Experience has shown that with an increase in scale comes also an increase in the number of features which are troublesome to identify and plot; and in a special type of survey such as a railway site, this point is all the more apparent. Because of this, the likelihood of photogrammetry providing a 100 per cent answer is remote—and indeed it has never been anticipated. The purpose of the experiment was to find out not only the degree of precision possible, but also the percentage of work which must be left for the ground surveyor to complete. Assuming that perhaps 20 per cent of the detail would have to be supplied by ground methods, it was still considered that the speed with which the 80 per cent could be produced by photogrammetry would more than justify the undertaking. The work of completion on the ground would be greatly simplified by the existence of the instrument-plotted detail, and would largely be a matter of direct measurement and offsetting.

When very large-scale surveys are under consideration, it is sometimes easy to forget that the topographical aspect has been replaced by an engineering and indeed sometimes by an architectural one. Tolerances, instead of being quoted in feet or meters, are in terms of inches. As this railway survey was concerned only with planimetric position, and needed no height values in the form of contours or spot heights, it was thought possible to adhere to these very tight specifications. For a plan at this scale, elevations are normally required to an accuracy of a decimal of a foot, which is outside the province of photogrammetry, and they could only be supplied by precise levelling on the ground.

The small tolerances for planimetric position also affect the provision of the ground control, because the accuracy of a photogrammetric map or plan is no greater than that of the control on which it is based. Only the most precise methods can be used. Constant interruption and sometimes vibration go hand in hand with normal railway surveying. Fortunately in the provision of the control for the air photographs, the network can lie almost entirely outside the railway, which is a distinct advantage. In any case, the amount of control required is comparatively small, and its supply presents little difficulty.

The exposure of photographs at pre-determined air stations is exceedingly difficult from such a low altitude as 1,600 feet, and would result in a high percentage of failure. It has been found safer and less costly to carry out photography first, and locate the ground control according to the disposition of the photographs. The most definite points on the photographs can then be chosen and the ground values obtained. In this way the danger of poor representation of a control point is avoided.

Fifteen exposures were needed to cover the Bournemouth site, taken in two flight lines because of a curve in the track. The control points were selected from detail in the roads and streets surrounding the site, and were fixed by precise theodolite traverse. As previously stated, the accent on this job was planimetry. Height control was only necessary to an order sufficient to ensure orientation without plan displacement. The co-ordinates of the control points were related to an arbitrary local grid system, and plotted on to the material specified by the railway engineer—good quality Whatman paper mounted on strong Holland backing and supplied in a continuous roll. Precise scaling was achieved by relation of the A.5 instrument co-ordinates to the ground co-ordinates, and the 1:480 plotting scale was obtained by introducing a 1:2 ratio between Autograph and plotting table. The speed of the plotting was not great in this case, as it was the first example of this kind of work that had been undertaken, but even so, the section of line, just over a mile in length, was plotted in twelve working days. The site included, in addition to the station itself, locomotive sheds, and yards, a goods or freight station and sidings, main and secondary lines and numerous examples of complicated permanent way constructions and attendant detail. In fact, it constituted probably as severe a test as any for photogrammetry. The instrument work was completed without incident, and all overlaps were oriented and scaled to an accuracy of 9″ at natural scale. This was an overall accuracy; local precision was almost certainly higher on all clearly defined features.

Fair drawing and examination were carried out in the usual manner; and the plan was subjected to a ground measurement check, as it was necessary to learn to what precision the plotting had been done, and also to supply certain features that had been obscured by trees and deep shadow. All ground measurements when transferred to the plan showed no plottable error. During a discussion that was held with the railway authorities, it transpired that few faults could be found with the positioning of the detail, but certain small features of great importance in railway operation were missing.

Practically all the point and crossing detail was found to be in error. This was not due to any inaccuracy in plotting or control, but was the result of the wrong feature being recorded. From the railway surveyor's point of view, the "toe" of the switch and "nose" of crossing are the two important parts of permanent way detail, and these positions are always carefully surveyed. Unfortunately, neither of these features records well on air photographs, and the point that had in fact been plotted was the bar which actuates the switch. The positions of these bars in relation to the toe of the switch varies with the type of switch, and consequently the errors varied in proportion from about one to four feet. The plotted position of crossings was comparatively good, but it will readily be seen that the movement of a few inches in the lateral position could cause quite a large displacement in the longitudinal position of a crossing.

The errors caused by mis-identification took a number of interesting forms, but here again they could readily be corrected by someone with air-photo experience, during a subsequent ground check. In some cases, boundary fences had been shown with irregular shapes, but on ground examination, it was found that the foundations of the fences were in fact straight, and the fences themselves were leaning over badly, giving the impression from the air of an irregular line. In another case, slopes which had been shown under a line of trees subsequently proved to be piles of branches which had been cut off and stacked neatly underneath. Omission of many small drains and inspection covers was commented upon, and as the average railway site has a complicated system of these features, their absence from the plan was, from the railway point of view, quite serious. Study of the photographs showed that many of the smaller ones had not registered at all, and therefore could not be plotted.

Correction of the faults was, however, a relatively simple matter which was completed by the contractor's surveyor in ten days, when the plan was finally delivered to the Railway Company which then accepted it without further question, as a good and reliable survey.

Many of the pitfalls and mistakes could have been avoided had a closer liaison been maintained during plotting between photogrammetrist and railway engineer. The plan had been treated as a large cadastral survey, and as such had not included the many special aspects of railway work. There are a great many features included in a railway site that are not found outside railway property, and the railway engineers have evolved a system of presentation peculiar to their needs. If fuller information and some specimens of railway surveys had been available for study before the commencement of the Bournemouth survey, it is certain that most of the mistakes would have been avoided. Even so, the experiment had been more than worth while, for it had amply demonstrated that such work was possible by photogrammetric methods, and it remained only to evolve a technique based on the experience gained in this initial attempt.

There appeared to be two major problems, the solution of which would increase considerably the scope and effectiveness of the plotting, and thereby reduce the amount of ground work. Firstly—a clear division had to be made between the work that the photogrammetrist would undertake, and that which would be left to the ground surveyor. Secondly, some means had to be found of plotting the many small details which are not usually recorded clearly on an air photograph. The percentage of detail that can be supplied by instrument plotting naturally varies with the site, but as a general rule it may be expected that buildings will always be a source of trouble at 1:480 scale. In view of this, it was decided that the precise location of all buildings over 8 ft. high within the Railway property, should not be attempted from the photographs. Instead, some system of reference points should be instituted that would allow of a precise positioning by instrumental plotting, and also be located in such a way that the provision of the building detail would be a matter of simple offset measurement. Some form of ground marker could be laid near the building or buildings in such a position that its registration on the photograph would be good, and its location in respect of the building suitable for that feature to be fixed with a minimum of measurement. These reference points, when plotted on the 1:480 photogrammetric plan, would enable the ground measurements to be related to the photogrammetric work. This system was wholeheartedly approved by the railway engineers, and it could be applied also to such features as the piers of bridges and other details obscured in any way by trees or the canopies of stations, etc.

As even the finest lenses do not resolve many of the smaller details of railway installations, the possibility of accentuation of these features before photography was investigated. It became increasingly clear that a day or two spent in preparation on the site would pay handsome dividends at the plotting stage, in the form of a great increase in the amount of plottable detail, a greater precision and an improvement in output. At the same time, a knowledge of the site would be invaluable to the person responsible for the photogrammetric plotting.

The preparation work then, falls into two main categories—(a) the provision of markers for obscured or screened details and (b) the accentuation of those details that present only a very small face in the plan view, e.g., the previously mentioned track features, mile and gradient posts and the gratings and covers of drains. The presence of the railway engineer or his representative during the preparation work would enable him to indicate to the photogrammetrist any particular feature or detail needing special attention, and generally acquaint the photogrammetrist with the details and requirements of the projected survey.

When, in April 1949, British Railways, Southern Region, (formerly Southern Railway Company) placed a contract for a further survey, all the details of preparation and planning had been worked out in the light of the valuable experience gained on the trial area at Bournemouth. The new contract involved a survey of about three times the extent of the experimental one and concerned a stretch of line in the southern suburbs of London, on a busy route to the South Coast and also carrying heavy suburban traffic. Unlike the Bournemouth site, it was completely electrified.

The Railway Engineer's Department expressed its willingness to co-operate in the provision of the markers, and also the labor to carry out this work under the guidance of the photogrammetrist. The two approaches to the problem—the ground engineer's and the air surveyors'—were happily united in the common task of producing an accurate survey in a minimum of time. Information from the engineer was first-hand and on the spot, enabling the photogrammetrist to take any necessary steps to ensure the requirements being fulfilled.

The prepared program included eight distinct stages as follows:

(a) Visit to site in company with engineer to perambulate the section and learn the local geography.
(b) Laying of markers and accentuation of necessary details.
(c) Photography.
(d) Return to site, to compare photographic cover with actual ground features, and to make any necessary annotations for office guidance.
(e) Provision of ground control. (This may proceed simultaneously with Stage (d).)
(f) Instrumental plotting.

(g) Fair drawing and lettering.
(h) Field check of plotted detail and supply of features called for in specification, but not plottable on instrument.

The detailed activity at each stage is worthy of further comment as it will undoubtedly show the close co-operation between contractor and client, and also prove how effective the photogrammetric treatment can become when proper consideration is given to planning, and when all the essentials of the project are known beforehand.

STAGE (a)—INITIAL VISIT TO SITE

The Railway Engineer and the photogrammetrist in charge met on the site, and walked over the length of track concerned in the survey. The Railway Engineer, knowing the reasons for the survey and the exact use to which it was to be put, was in a position to indicate details that were not required, and others to which particular attention should be paid. At the same time, agreement was reached as to the point where the photogrammetric work would finish, and the ground surveyors take over. In this way, the photogrammetrist knew exactly the work involved and the engineer had a clear picture of the state in which the plan would be delivered to him, thus enabling him to plan his part of the work well in advance.

STAGE (b)—LAYING OF MARKERS AND ACCENTUATION OF NECESSARY DETAILS

The selection of the positions for the markers was done in a manner mutually satisfactory to the Air surveyor who would be plotting them, and to the Engineer who would be using them for the supplying of detail after the photogrammetric stage was complete.

The size of the markers is determined by the resolving power of the camera lens used, and the instrument in which the plotting is to be carried out. The style and form of the marker is determined by the nature of the surface on which it is to be placed. On hard smooth surfaces, the marker may be painted in white or yellow semi-permanent paint, but where grass or gravel or loose cinders are the base, paint is obviously unsuitable. In this case, small targets can be constructed, of wood or metal, painted white and fixed centrally to wooden pegs driven into the ground. Where it is possible to paint the markers directly on to the ground surface, e.g. concrete, stone, wood or metal, the exact point of reference must be indicated by a small metal spike or nail driven in to the head, so that it cannot be moved by unauthorized persons and will remain in position indefinitely. The Engineer will need to use these points perhaps several months afterwards, when the paint will have weathered away. The painting for the accentuation of otherwise obscure details need last only until photography has been completed successfully, whereafter loss of the marks by weathering or defacement will not jeopardize the plotting.

The operation of laying markers and targeting the smaller details was completed in one and a half days, the labor being supplied by the Railway Executive and working under the direction of the Engineer and the photogrammetrist. Details treated included permanent way, point levers, mile and gradient posts, bridge details, gullies and gratings, and other small items of railway equipment likely to have poor registration on the air photographs. Markers were also laid for signal boxes, station buildings and certain details under trees and in deep cuttings.

STAGE (c)—PHOTOGRAPHY

It was essential, for this project, that the photography be of the highest quality, and it was particularly fortunate that at the time, a Wild R.C.7. (f.1. 170 m.ms.) fully automatic plate camera was available, as it is an instrument particularly suited to this type of work, by virtue of the exceptional definition of its "Aviotar" lens and its automatic operation. The availability of this camera permitted an increase in the flight altitude to 2,200 ft. which gave greater coverage with no loss of accuracy, and less danger of ground movement. Even so, it was still necessary to fly as slowly as possible, and the machine used was a D.H. Rapide flying at 100 m.p.h. Exposure was 1/300 second at f5.6 on Gaveart Micropan plates which were subsequently developed in Kodak D 76 for 20 mins. at 69°F. The resulting negatives were bright and clear and ideal in every respect.

FIG. 1. Specimen exposure at contact scale. Height 2,200′, R.C. 7. Plate Camera, 170 mms. f.1.

STAGE (d)—COMPARISON OF THE PHOTOGRAPHIC COVER WITH DETAILS ON SITE

Perambulation of the site with a set of enlargements enabled the photogrammetrist to compare the photographic evidence with the features in nature, and this experience was invaluable at the plotting stage. At the same time, the photographs were annotated and features further described where necessary. Sketches and ground photos were found to be useful for recording such details as the types of signals, values on mile and gradient posts, etc., all of which must be included on the final plan. Ground photographs in particular gave the operators who had not visited the site a very helpful guide to the nature of the area being plotted. The work of annotation, photographing and taking of notes took only one day to complete.

STAGE (e)—GROUND CONTROL

This stage was carried out soon after completion of photography, and followed the normal character of precise theodolite traversing. The work involved rather a large number of instrument stations, owing to the layout of the street and road system in the area surrounding the railway. However, it was completed satisfactorily in three weeks, by one surveyor with two assistants. The object, as in the earlier Bournemouth job, was the fixing of four co-ordinated points per photographic overlap, which was achieved by relating the chosen points to the traverse network by angles and measurements. As the survey was to fix planimetry only, the height control, which was carried out independently, was to a comparatively low order of accuracy, being sufficient only for the orientation of the stero-models without plan displacement.

STAGE (f)—INSTRUMENT PLOTTING

As previously stated, the Wild A.5. instrument was chosen for the work and the set-up was as follows: Photographs taken with the Wild R.C.7. need no lens or format compensation for use in the A.5., as the two pieces of apparatus have been designed to work together and a very fine combination it is! Although the original negatives could be used directly in the instrument, it is the policy generally to subject this valuable material to as little handling as possible, so diapositives were made for instrumental use. In any case, a negative for use in the instrument needs different treatment which renders it unsuitable for the taking of paper prints and enlargements. Diapositives are made by direct contact printing which involves no process likely to cause distortion and subsequent errors.

The plotting scale of 1/480 required a machine plotting table ratio of 1:3 giving a machine scale of 1/1,440 and the flying height of 2,200 ft. (670 m.) when reduced to this scale, results in an instrument altitude of 465 m.ms.

The control supplied by the ground surveyor, for the orientation of the models was not plotted until the sheets had been thoroughly seasoned by festooning. Some of the control points, when plotted at this very large scale, were almost a meter apart, so that any distortion in the base sheet would have made satisfactory orientation impossible.

The actual plotting of the detail presented no difficulty whatsoever, and the first section, covering three-quarters of a mile of track and involving 5 stereo overlaps, was completed in exactly one week. This portion of the site included five main tracks with the usual interconnecting switches to be found in the neighborhood of stations, together with all the other details such as signals, re-

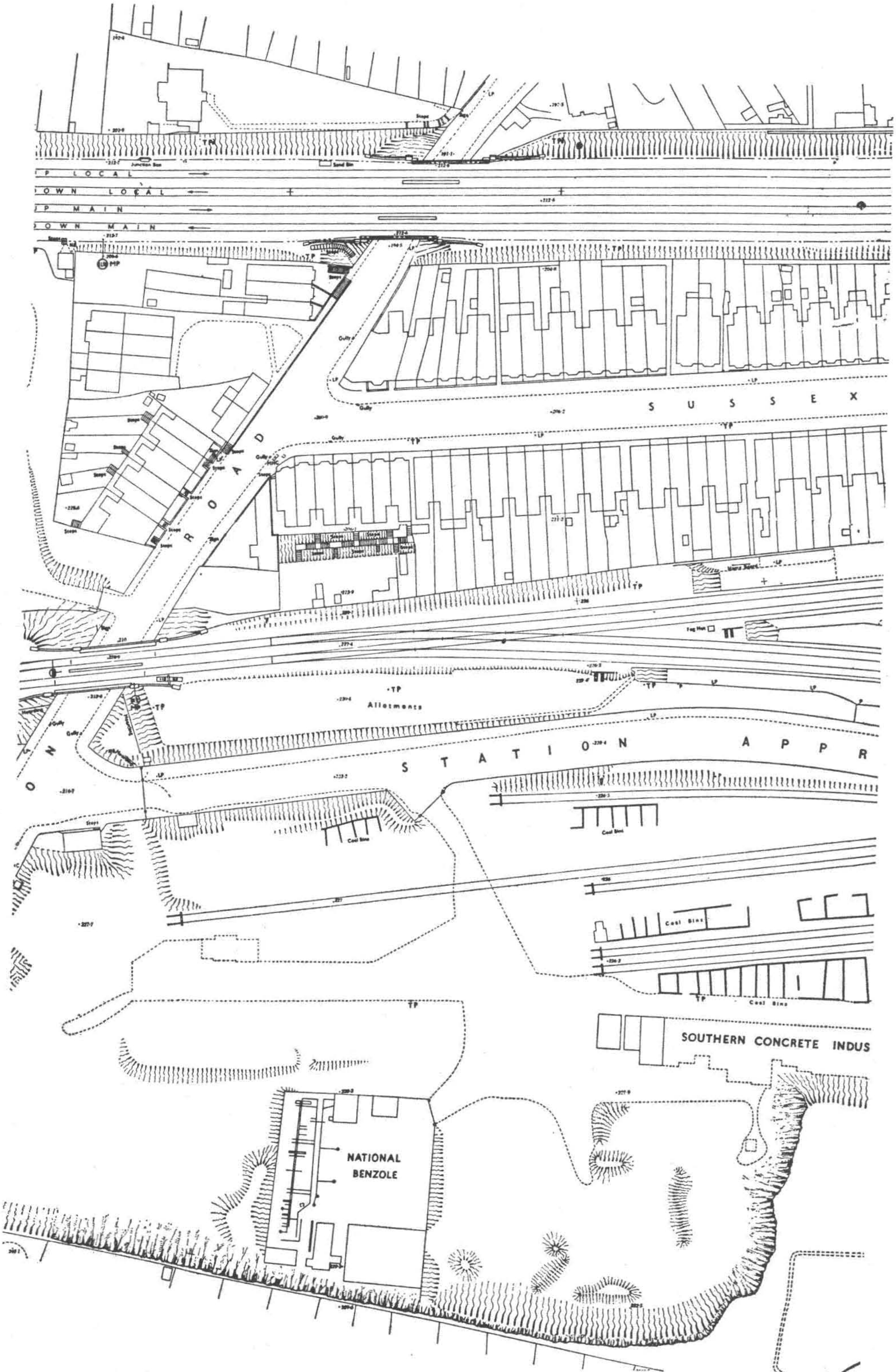

FIG. 2. A part of the original 1/480 survey reduced to approximately 1/1,200.

taining walls, slopes of cuttings and embankments, in fact all the features, however small, that existed in the area being surveyed. The accentuation of the smaller details proved most effective and enabled a very high percentage of the detail to be plotted. In the first section for example, the only features that could not be plotted were the ground line of an overhanging signal box, and the piers of two bridges, and one or two property fences obscured by trees. These had been anticipated when looking over the site in the first instance, and markers had been laid so that the supplying of the missing detail would be simply and speedily carried out.

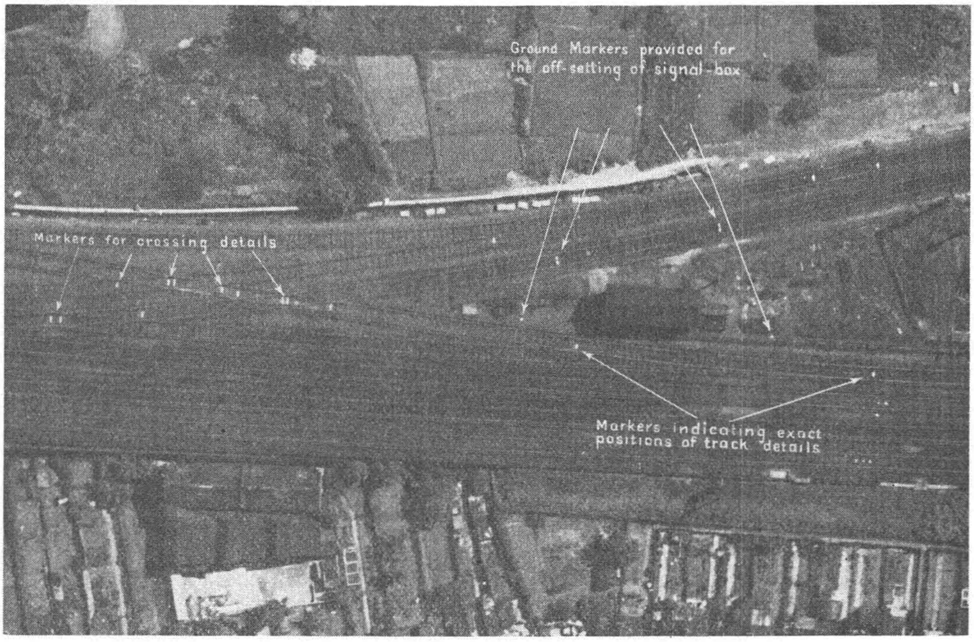

FIG. 3. Five times enlargement from part of original negative showing typical junction and signal box markers.

STAGE (g)—FAIR DRAWING

This process is quite straightforward and involves no technicalities, the main consideration being the accurate inking of the detail plotted by the A.5. and the presentation of detail in a manner in accordance with normal railway practice. It is advisable for this work to be done by personnel who have been concerned with the plotting, for queries will inevitably arise at so large a scale.

STAGE (h)—FINAL FIELD CHECK

In this final stage of the work, the survey was given a percentage check for reliability, and details were supplied where called for in the specification and impossible to record accurately by instrument plotting. Careful measurement between series of ground markers indicated the high precision of the work, for no plottable errors were found. As was to be expected, certain detail, although plotted by the instrument, contained elements of doubt, and this final visit enabled all the doubtful points to be cleared up satisfactorily. When all necessary amendments had been made, the plan was delivered to the railway authority.

This project has proved to be a most satisfactory and interesting undertaking for photogrammetry, and has shown that the technique used has overcome most of those problems which appeared so formidable at the outset. With the assistance and guidance of the Railway Engineer's Department, a 1/480 plan has been produced almost entirely by photogrammetry to a standard of accuracy acceptable for railway engineering work. This is a remarkable step forward in the photogrammetric field, as well as being a revolutionary departure in railway engineering. It is to the credit of such a farsighted department of British Railways that they were prepared to consider a break from accepted methods, and so willingly to assist the contractors. In so doing, they have created a precedent that may be claimed as an important step forward in photogrammetric technique, while at the same time providing a means of greatly accelerating and simplifying the preparation of accurate plans in the extensive program of new construction and maintenance of British Railways.

THE STEREO-MOSAIC, A NEW MAPPING TECHNIQUE

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EVER since maps were first used, man has been trying, usually with poor success, to introduce the third dimension by such devices as topographic symbols, hachures, or contour lines. Aerial photography viewed with a stereoscope offered the best solution yet devised, but due to the many displacements and scale variations inherent in aerial photos, they were very difficult to use as maps. The mosaic, using only the center of each photo, solved some of the difficulty with displacements and scale variation. However, stereo-vision, the aerial photo's most valuable asset, could not be used with mosaics, so the mosaic has been little used. For a number of years, there has been a search going on, both in military and civilian circles, to find a new type of map which would include both the advantages of the aerial photo and of the planimetric or contour map. Several solutions have been found of which the stereoscopic contour map, using the anaglyph principle, and the mosaic with a planimetric map over-printed, are the most notable. A way has now been found to view mosaics stereoscopically.

This new method has been occasionally used with vectographs, and involves the compilation of a left-eye mosaic and a right-eye mosaic to be viewed simultaneously. If a large mosaic is to be made, it must be broken up into panels, approximately 20″×30″, which can be placed separately under a large mirror stereoscope. In our first trial, we have used a photo scale of approximately 1:31,680, and made the panels $7\frac{1}{2}$ degrees of latitude by 15 degrees of longitude, which gave approximately the above dimensions. It was necessary then, after assembling the required photos, to cut each photo in half along a line perpendicular to the line of flight, which in our case was north and south.

MAKING THE MOSAICS

The north and south halves are placed in separate piles for use in separate mosaics. A controlled mosaic is then laid, using only the south halves, on the first panel. In order that map symbols may be inked on this mosaic, and later corrected where necessary without damage to the emulsion, a coat of clear lacquer is applied. Standard map symbols are then inked on the mosaic. Picture-pointing is done as much as possible to locate land lines correctly.

In order to compose a stereo-mate for this mosaic, it is then necessary to use

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