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NON-TOPOGRAPHIC PHOTOGRAMMETRY IN A COMMERCIAL MAPPING COMPANY

O W Cheffins Fairey Surveys Ltd

ABSTRACT

A total of 38 contracts involving non-topographic applications of photogrammetry has been carried out by Fairey Surveys Limited over a period of 15 years (1963 - 1978). Nine typical examples are described to illustrate the scope of the work and giving reasons why the jobs were done. Details of the photography used, the accuracies achieved and an indication of the effectiveness of the photogram--metric method are given in each of the cases.

INTRODUCTION

The first serious request to our company for photogrammetric work of a non-topographic nature was in 1963. Since then we have carried out 38 contracts which fall into that category, although they have only amounted to 0.3% of our total photogrammetric revenue earnings, and all but 8 of them have been small, i.e. 100 manhours or less. No two jobs have been the same, so the amount of pick-up time is usually quite significant and adversely affects the cost. The 8 comparatively large jobs, each taking up to 1000 manhours, have enabled us to develop a certain amount of streamlining in the production processes.

11 out of the 38 jobs (29%) were experimental, having been commissioned by our clients in order to assess the value of photogrammetry, but insufficient feed-back of information prevents us from making a true quantitative comparison between photogrammetry and other methods.

This paper is an attempt to assess the effectiveness of non-topographic photogrammetry by outlining a selection of the work which we have completed over the past 16 years. The applications are described in ascending order of photographing range.

RESEARCH IN ORTHODONTICS (1) (3)

We have produced more than 300 life size contoured drawings of children's faces over a period of 10 years. The subjects were like sexed twins, 26 boys and 26 girls and the drawings were used to monitor their facial growth for varying periods between the ages of 9 and 16 years in connec--tion with research in orthodontics at Addenbrooke's Hospital, Cambridge, by Professor P H Burke.

Stereometric photography was obtained using a pair of specially adapted multiplex projectors at a taking distance of 400mm. Multiplex equipment was also used for plotting contours at 2mm vertical intervals and certain other features at natural scale. The accuracy of the multiplex system is reckoned to be such that x, y or z values in the model space can be determined to within $\pm$0.3mm (r.m.s.e.). However, repeated photography and measurement of certain of the orthodontic subjects indicated that the accuracy may be only half as good in this application, probably because one is dealing with soft tissues.

Photogrammetry was favoured because of its convenience when compared with alternative ways of obtaining such detailed information over such a long period. Whilst it is recognised that the use of multiplex objectives for taking photography is not ideal, it is nevertheless an inexpensive method of obtaining a so-called exact photogrammetric solution. The cost-effectiveness in this case is good, and the regular flow of work over a period of several years enabled us to deal with it efficiently.

RECORDING THE SHAPE OF A STEEL MOULD (2)

The multiplex method was also used for producing a detailed record of an industrial respirator mould. The object consisted of two matched female components and a male core, all milled out of solid steel. It was only necessary to define the shape of one of the female moulds, which measured 0.4m x 0.4m x 0.1m overall. It could be covered by a single stereoscopic overlap taken at a distance of approximately 400mm.

Photogrammetric measurement was carried out on the multiplex by reprojec--ting the photography and orienting the model at a scale of 1:1. A network of depth values was recorded at the intersections of a square grid at 6.35mm spacing over the model, and contours were plotted addit--ionally at vertical intervals of 2.54mm. Significant detail such as lines and dowel holes were also included.

The intrinsic accuracy of the multiplex system, namely ± 0.3mm, was acceptable to our client for the purpose of this measurement. He was also satisfied that the photogrammetric approach was cost-effective and gave a more detailed record of the mould than could have been obtained by other methods, in spite of the fact that the object was very solid and appeared to be ideal for measurement with a feeler gauge.

<u>MEASURING DISTORTIONS IN AN AIRCRAFT FUSELAGE</u> (2)

We carried out an experiment on behalf of the Aircraft Research Depart--ment to see how effective photogrammetry would be for measuring air-liner fuselages in the vicinity of the static vent plates, where distortions might affect the calibration of the altimeter and airspeed indicator. Information would have been needed for a whole fleet of similar airliners, and it seemed that the photogrammetric method could be used without having to take the aircraft out of service to do the measurement.

Our contract included the cost of designing and constructing a mobile cradle for supporting the Galileo Santoni "Special A" stereometric camera used for taking the photography. This cradle incorporated a reference frame and the whole device, with the camera mounted, could be manoeuvred very quickly to the static vent areas so that photography, complete with control, could be obtained in a space of a few minutes.

The experiment consisted of a repeatability test, rather than a check on the accuracy of photogrammetry against other forms of measurement. We took a series of stereoscopic pairs of photography covering the static vent area of one particular BAC 1-11 airliner. After exposing each pair, the mobile supporting cradle was moved right away from the aeroplane, and then taken back again to be repositioned.

Each pair of photographs was successively oriented in a Zeiss (Jena) Stereometrograph and a set of depth (Z) readings was recorded at the intersections of a 10mm x 10mm grid over the area of 1 sq m surrounding the static vent plate. The values from each set of observations were then compared and an analysis of the differences was made. We found that the repeatability of measurement of the whole system, i.e. camera and photogrammetric plotter combined, was in the order of ± 0.36mm (r.m.s.e.) in Z.

Since completing the experiment and submitting the results to the client, together with a report, no further photogrammetric work has apparently been commissioned. However, had it become necessary to deal with the whole fleet of aeroplanes, as envisaged, such a detailed measurement could not have been done easily by direct methods without taking the airliners out of service, and therefore the effectiveness of photogram--metry in this application seems to have been proved.

PRODUCING TEMPLATES FOR INSULATION CLADDING (6)

During the course of building Heysham "A" nuclear power station, it was realised that close-range photogrammetry could be an effective way of obtaining measurements on the spherical domes of the two reaction chambers, for the purpose of designing insulation packs. These are made of stainless steel laminations which have to fit accurately in between 324 vertical stand pipes (330mm diameter) and 52 control rods (250mm diameter) which penetrate the surface of each dome, over an area of approximately 100 sq m.

We were asked to submit proposals for a photogrammetric solution and decided to use a Wild C40 stereometric camera at a range of approximately 1.5 metres, as dictated by the amount of clearance above the surface of the dome. After carrying out some photographic tests on site with the C40 camera supported on the standard tripod, we found that a special camera platform would be desirable, (i) to ensure that there was no obstruction in the field of view and (ii) to speed up the camera setting operation for taking the 200 pairs of photographs needed to obtain stereoscopic cover of each dome. The special mounting which we made was a four-legged platform 2m x 2m resembling a coordinatograph, with a sliding cross bar to hold the C40 camera in a downward-pointing attitude. From each positioning of the platform, 6 stereo-pairs could be taken by sliding the cross bar to the required locations. A scale was introduced into the field of view and lines were scribed on the surface of the dome to mark where the lowest level of laminations and the fixing studs would be attached.

Photography on the first of the two reactor domes was hampered by the presence of a large number of props which had had to be positioned unexpectedly in order to remedy slight sagging in a temporary roof structure, and because of which we could not take all the planned photography from the special platform. The dome of the second reactor was in a less advanced state of construction when we took the photography and so it was much less of a problem.

Most of the photogrammetric plotting was done on a Zeiss Jena Stereometrograph, having first made enlarged diapositives of the photography to give an equivalent principal distance of 152.36mm, (the camera p.d. being nominally 64mm). Template drawings were plotted at natural scale, being a total enlargement of 28 times from the original photography.

The accuracy of the template drawings was tested by our clients, who sampled approximately 10% by laying them directly on the domes and comparing them with the scribed lines on the surface. All these drawings fitted to within the prescribed tolerance of $\pm$1.6mm.

Had photogrammetry not been used, the template drawings would have been made by a direct "wall papering" method which would have meant 4 men occupying the site continuously for at least 4 weeks and thus holding up other construction work. As it was, photography of the two domes was achieved in 10 days, some of this time being over a long week-end holiday period, when all other work on the domes was shut down. At the time of the survey, it was estimated that the photogrammetric method cost between 1.3and 1.4 times the traditional "wall papering" method. However, every week's delay in the commissioning of the generating station was estimated to cost 100 times as much as the whole photogram--metric survey, and therefore, the saving of two weeks was adequate proof of the cost-effectiveness of photogrammetry.

MONITORING PRESSURE VESSELS UNDERGOING TESTS

Welding techniques have been tested by subjecting model pressure vessels to heat and pressure, and then measuring them to check for distortion. At one time, a reasonably compact model vessel (1.2m in diameter) was in use at the Berkeley Nuclear Laboratories of C.E.G.B. Points marked on its surface in the vicinity of a cluster of dummy nozzles were coordinated by means of close-range triangulation using a collimator positioned at either end of a lathe bed. The vessel was then moved into a safety pit where it was pressurised up to a certain level. It was then re-erected in the laboratory for re-measurement.

Subsequently a much larger pressure vessel was developed which was too cumbersome to keep moving in and out of the laboratory. It was therefore decided to keep it in position in the safety pit for the duration of the tests and to measure it in situ. However, the test panel on the vessel, facing downwards into the pit, could not be observed with the collimator that had been used on the smaller vessel because of space restrictions and other considerations. We were approached to suggest how the measurement could be done by photogrammetry. The cameras which we decided to use were in fact two modified, normal-angle, Kelsh projectors, which would be placed on the floor of the safety pit on special mounting plates so that their upward-pointing attitude would be virtually the same every time that photography was required. The test panel could be covered by a single overlap taken at a range of 1.8m. Control comprised three pre-marked points forming an equilateral triangle of known length sides immediately outside the test panel: a vertical marker with graduations was also attached to the centre of the test panel as a check on Z measurements.

A programme of pressure and heat tests carried out over a period of four or five years was successfully monitored, in part, by photogrammetry, using photography taken by the C.E.G.B. themselves whenever they required measurements, which we did for them by setting up the overlaps in a Wild A8 stereoplotter. The requirement was to provide three-dimensional coordinates for a number of pre-marked points on the surface of the panel and on the dummy nozzles.

Photogrammetry in this application proved to be effective because there were not adequate facilities for other forms of measurement in the test pit. The fact that our client pursued the method over a period of several years is also an indication that it was satisfactory.

PROFILING EXPOSED ROCK SURFACES IN A HYDRO-ELECTRIC POWER TUNNEL (7)

Information about the roughness characteristics of tunnels driven through rock was required as part of a long term study into the design of hydro-electric installations being carried out at the Imperial College of Science and Technology, London. As a part of the investigations, a strip of overlapping close-range photography was taken of one side of a length of a 5m diameter, unlined tunnel that had been driven through rock. The camera was non-metric, being a Linhof Super Technika with a Schneider Symmar lens of 150mm focal length: the negative format size was 125mm x 100mm. A specially made base-board mounted on tripods and aligned parallel to the tunnel walls was used to support the camera and to move it accurately from one taking station to the next. Photographing range was 3.8 metres and 13 stereoscopic overlaps were provided to cover a continuous stretch on one side of the tunnel.

For control purposes, two sections of a levelling staff were placed respectively in a vertical and horizontal position in the field of view of each stereoscopic overlap for use as scale bars. Also, depth (Z) values were determined for points marked at intervals along the tunnel walls, relative to a known datum line, by direct measurement on site.

We carried out photogrammetric plotting from the photography by orienting successively taken stereoscopic pairs in a Zeiss Stereoplanigraph C8. We produced 16 longitudinal profiles at tangential intervals of 152.4mm, related to a cylindrical datum surface.

Differences between profiles plotted from adjacent stereo pairs indicated that an accuracy in the order of ± 6 mm r.m.s.e. was being achieved for the shape of the rock profiles.

The photogrammetric method of obtaining the rock profiles was chosen by our client because photography was the fastest method available for recording the data in such detail, as required for the analysis. It can therefore be concluded that photogrammetry was effective in this application.

PROFILING A DISTORTED BRICK ARCH

Settlement had resulted in distortion to a low brick arch bridge which carried a commuter railway over a narrow road in a busy London suburb. The remedy planned by British Railways for strengthening the bridge without decreasing the restricted headroom any more than necessary, was to prepare an armoured lining which followed closely the distorted shape of the arch. We were asked whether the required profiles could be constructed photogrammetrically, in order to avoid closing the bridge to road traffic.

Using a Zeiss phototheodolite, with the objective suitably stopped down, we took two stereo pairs of the bridge looking through the arch from the roadway on either side. The underside of the arch was illuminated by discharging large magnesium flash bulbs. Photography was completed in an hour or two early on a Sunday morning in May when there was virtually no road traffic and before the trains were running.

Control for the survey comprised distances measured between signalised markers placed on each side at the springing of the arch in the positions where profiles were required. The height of the brick cornice above ground level at each of the four corners of the bridge was also measured and used as control.

Both overlaps of photography were set up in a Zeiss Stereoplanigraph C8 and the profiles, at the locations indicated by the signalised markers, were plotted at a scale of 1/12. Each profile was done twice indepen--dently from the photography taken at either end of the arch, and this gave an indication of the accuracy which was being attained - found to be in the order of ±10mm.

The whole operation, including photography and production of the profiles was carried out over a period of two or three weeks and was regarded as satisfactory. Photogrammetry in this application meant that there was no disruption to road traffic while the measurements were being taken. Direct methods would have involved erecting staging across the road which would have had to be closed for the purpose.

SHAPE SURVEYS OF COOLING TOWERS (5) (6)

Following the collapse of one cooling tower, which was attributed to deformations in the constructed shape, we were invited by ICI to tender for carrying out shape surveys of three others. Photogrammetry appeared to be the most practicable method of doing the work and our proposals on these lines were accepted.

We took photography of each tower with a Wild RC5A wide-angle aerial survey camera mounted on its side, from suitable camera stations either at ground level or in the bucket of a mobile hydraulic platform which could be raised up to a height of 21 metres. Complete stereoscopic cover of the outside of two of the towers was obtained with six and seven overlaps respectively, but obstructions near to the third tower forced us to take the camera to a much closer range than we had planned and in consequence, as many as fourteen stereo pairs were needed.

Control was established by conventional triangulation, fine points of recognisable photo-detail being coordinated from theodolite stations on measured base lines.

Photogrammetry consisted of orienting the photography in a Zeiss Stereoplanigraph C8 to plot ring contours and certain identifiable detail features. The plotted contours were then compared with truly circular design contours and from the differences, developed surface drawings were constructed to show lines of equal radial departure from the ideal shape.

Measurement of the towers by methods other than photogrammetry would have taken longer and been more difficult, and apart from some reservations by our client regarding the accuracy which we achieved (estimated to be ±0.04m) the results were reasonably satisfactory.

SURVEY OF VERTICAL CLIFF (4)

We had carried out a terrestrial photogrammetric survey of the north face of Edinburgh Castle Rock several years earlier with the same equipment as that used for the cooling towers, namely a Wild RC5A aerial survey camera on its side for photography and a Zeiss Stereo-planigraph C8 for plotting, with control established by traditional ground survey methods. However the subject was somewhat different and contours ("isometrons") with respect to a vertical datum plane were plotted at 0.25m horizontal intervals. The photogrammetric results were to be used in conjunction with other survey work for carrying out rock stabilising measures.

Four overlapping pairs of photographs were taken with the Wild aerial survey camera from the elevated bucket of a hydraulic platform, at a horizontal range of approximately 100 metres, which gave us a negative scale of 1/650. We were required to produce the survey at a scale of 1/50 (an enlargement of approximately 13 times). After the plot had been produced, the engineers realised that it was going to be difficult to relate the line work to the complex structure of the rock face without reference to the photography. Therefore, we were asked to provide an orthophoto at the same scale as the plot. This assisted to some extent, although, because of the great enlargement factor entailed (x 13) there was still some difficulty in interpreting detail. However, apart from this, the use of photogrammetry proved to be effective.

CONCLUDING REMARKS

Non-topographic applications of photogrammetry have contributed only a small amount to our revenue earnings during the past 16 years, although we have carried out a wide variety of jobs in this category. Most of them have been fairly small - taking less than 100 manhours each - and pick-up time in some cases has diminished their cost-effectiveness. However several of the contracts, including some described in this paper, have been comparatively large and as well as being commercially worth-while have shown that photogrammetry is an effective method of measure-ment in fields other than aerial survey.

The facial contouring, plotted from photography provided by our client, gave us a steady flow of work over a period of about 10 years; we became thoroughly familiar with the requirements and were able to develop an efficient production system. Likewise, the monitoring of pressure vessels, although not so continuous, was done over several years.

The production of insulation cladding templates for the reaction chambers was another contract of substantial size and despite unforeseeable difficulties which confronted us when we came to take photography of No. 1 reactor dome, causing some problems at plotting stage, the work on No. 2 reactor dome went according to plan and the operation, overall, was successful. In comparison with direct methods of producing the templates, photogrammetry cost 30% to 40% more, but since it had the advantage of not holding up other important construction work, photo-grammetry proved to be cost-effective.

Another large contract was the plotting of shape surveys for three cooling towers. We also met some difficulties with the photography, but they were largely overcome at plotting stage and the net result was satisfac--tory, apart from reservations by our client about the accuracy which we achieved.

The other jobs described in this paper are isolated tasks where photogrammetry was found to be a more convenient method of obtaining information, than direct measuring techniques would have been.

A summary of the applications described in this paper is given in Table I.

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TABLE I
EXAMPLES OF NON-TOPOGRAPHIC APPLICATIONS OF PHOTOGRAMMETRY CARRIED OUT BY FAIREY SURVEYS LIMITED

APPLICATION	CAMERA	CAMERA P.D.	BASE LENGTH	RANGE (R)	ACCURACY (R.M.S.E.)	NO. OF PAIRS TO COVER	REMARKS ON COST EFFECTIVENESS
Contouring children's faces for research in orthodontics.	A pair of modified Multiplex projectors	28 mm	0·17m	0·4m	±0·69mm R/580	1 × 300 faces	Very good. Direct measuring of the subjects would not be acceptable.
Recording the shape of a steel mould.	A pair of modified Multiplex projectors	28mm	0·17m	0·4m	±0·3mm R/1333	1	Very good compared with direct methods, which would be less detailed.
Measuring distortions in an aircraft fuselage near to the static vent plate.	Galileo-Santoni "Special A" stereometric camera	150mm	0·56m	1·5m	±0·36mm R/4167	1	Good, as airliners would not have to be taken out of service.
Producing design templates for making insulation cladding on domes of nuclear furnaces.	Wild C40 stereometric camera	64mm	0·4m	1·5m	±1·6mm R/938	200 × 2 domes	Good, because construction work was not held up while measuring was done.
Monitoring pressure vessels undergoing tests.	A pair of modified Kelsh projectors	210mm	0·76m	1·8m	±0·4mm R/4500	1	Very good. Object was in a confined safety pit, making direct methods impracticable
Profiling exposed rock surfaces in a hydro-electric power tunnel.	Linhof Super-Technika press camera	150mm	0·76m	3·8m	± 6mm R/633	13	Good. Photography was the fastest way of collecting data in such detail.
Profiling a distorted brick arch bridge for designing a reinforcement lining.	Zeiss phototheodolite	162mm	2·74m	15m	±10mm R/1500	2	Good. Bridge did not have to be closed to traffic while measurement was done.
Plotting shape surveys of cooling towers to check for distortion.	Wild RC5A wide-angle aerial survey camera	152mm	10m to 80m	20m to 180m	±40mm R/2500	6 to 14 ×3 towers	Good. More detail of shape could be obtained than by direct methods.
Surveying a vertical cliff for rock stabilising measures.	Wild RC5A wide-angle aerial survey camera	152mm	23m	100m	±100mm R/1000	4	Very good. Direct methods would not have produced as much information.