The Photogrammetric Method as a Means of Providing Highway Engineers With an Integrated And Complete System of Surveying

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This paper was written to demonstrate that the photogrammetric method is a science capable of providing highway engineers with an integrated and complete system of surveying for obtaining the qualitative information and quantitative data about the ground surface required for the route location, preliminary survey, design, location survey, and construction stages of urban highway projects. All except the last two stages can be completed prior to a ground survey party occupying the actual centerline of any particular project.

Urban projects are emphasized, because it is on this type of project that maximum utilization of the photogrammetric method can be realized. This is not to say, however, that variations of, or use of portions of, this method cannot be economically applied to all other types of highway projects, as is now being done by a substantial number of highway departments.

IT IS the opinion of this author that in the past too many highway engineers have used photogrammetry only to provide highway information in the traditional form which was previously provided by standard ground surveying methods, rather than realigning conventional highway engineering procedures with the more integrated and complete system of information that can be prepared through the application of the photogrammetric method. The traditional approach has been to establish a centerline (or baseline) on the ground and proceed to tie physically all pertinent information (planimetric and topographic engineering data and cross sections) to this line. This approach places definite restrictions on any project.

A more modern approach is through use of a plane coordinate system whereby a wide band of accurate dimensional data (planimetric and topographic), all surveyed to a common coordinate system, is supplied to the highway engineer, allowing consideration of all aspects of any highway alignment within the band. This approach completely eliminates the necessity of a ground survey of the centerline of any route prior to the actual construction of the highway. The photogrammetric method is presented in this paper as the method capable of providing the information essential to facilitate this coordinated approach. Most highway departments employ portions of this method in their present operaions, but it is the integrated and complete approach which is emphasized in this paper.

It might be reiterated here that photogrammetric engineering applied in the highway engineering field is a highly technical and complicated science which requires a pro-

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fessional approach and strict control throughout each phase of the method. The personnel involved must have a thorough knowledge of both photogrammetric and highway engineering procedures.

STAGE I—RECONNAISSANCE SURVEY

It is not the intention of this paper to dwell on this stage. It is sufficient to state that the application of photo interpretation methods and photogrammetrically made measurements to the reconnaissance survey of area and route locations, supplemented with drainage and hydrology investigations, is indispensable to an efficient highway program and determination of the best route for each highway.

STAGE II—PRELIMINARY SURVEY OF SELECTED ROUTE

For this stage the location and design engineers require a wide corridor of information to appraise all interrelated problems involving one, or perhaps two or more, projected feasible locations for the highway within the selected route corridor.

To satisfy these requirements the photogrammetric engineer can supply topographic maps at a scale of 200 ft per in. with contours on a 5-ft interval. In this early stage of the project survey and design work the photogrammetric engineer is in the advantageous position of being able to carry out these mapping procedures based on control which forms part of the national network of horizontal and vertical control existing within that particular province or state. This should be done. The basic horizontal control would be measured using electronic distance-measuring instruments between properly placed monuments (station markers), and would be presented in plane coordinate form according to the specifications of the national network. It is suggested that this basic control for photogrammetric work be of second order accuracy, with the permanent monuments for station markers spaced every 1 to 2 miles and in specifically important areas along the route corridor being surveyed.

Under direction of the photogrammetric engineer, each station marker in the survey area would be targeted, photographs of the route taken, and standard photogrammetric procedures of aerial triangulation and mapping carried out to compile the topographic maps required. Then, in presenting the maps to the location and design engineers, if time is taken to inform them regarding the full value and accuracy of the maps and the ramifications of a plane coordinate system, they can use the maps for projecting proposed highway location alternatives along the surveyed route, measuring control points and computing a precise description of the horizontal and vertical alignment, and for the basic planimetric presentation of location and design.

Thus the necessity for survey staking of the centerline on the ground to substantiate the findings of the location and design study has been completely eliminated. Results of this study, of course, determine the best location for the highway on the selected route.

It might be noted here that if the digital terrain model (DTM)[1] approach to location and design of highway projects becomes further developed and accepted, it will be a rather simple procedure with present-day digital measuring and recording equipment to use the X, Y, and Z dimensions as measured by photogrammetric equipment at the same time as the stereoscopic plotting of the 200 ft = per in. scale topographic maps.

STAGE III—DESIGN

The design highway engineers require a band of planimetric and topographic data to design the highway and to prepare detailed construction plans. The photogrammetric engineer can supply a topographic map of 40 ft per in. scale (1:480) with contours at

[1]The digital terrain model is a concept developed at Massachusetts Institute of Technology in which the entire route survey corridor is covered by a network of points whose X, Y, and Z coordinates are known and stored in a computer. Further refinements of the concept involve assigning series of weights to these points according to one or more classifications, such as land costs, soil type, and so forth, and the subsequent application of the data to highway location, design, and construction.

an appropriate interval and cross sections measured photogrammetrically. He again finds himself in the advantageous position of being able to request control for this large-scale mapping which, if properly spaced, monumented and targeted on the ground, (a) will form the basic X, Y, and Z coordinate control for the photogrammetric work; (b) will form the basic control for all further highway project surveys, such as land (property) surveys, utility relocation, municipal and soil investigations, and the subsequent location and construction surveys; and (c) will supplement the national network of basic control within that province or state.

To insure that this control remains unaffected as much as possible by future construction of the project, it is necessary that it be approximately positioned jointly by the photogrammetric, design, and construction engineers. The horizontal control, measured with electronic distance measuring instruments, would be based on the second order control as established during Stage II, and would be measured to at least third order accuracy with survey station markers set every 500 to 1200 ft (with increased density of markers at proposed interchange sites) along the route band of topography. The vertical control would, at this time, be monumented and surveyed by precise leveling methods with bench marks every 0.2 to 1.0 mile along the general route.

Under the direction of the photogrammetric engineer, the standard photogrammetric procedures would be carried out. The horizontal and vertical control points would be targeted, flying to take the large-scale photography would be done, and the aerial triangulation and stereoscopic compilation of the maps and measurement of profile and cross sections with precision photogrammetric instrument would be accomplished. The large-scale topographic maps are passed to the design engineers along with prints of the aerial photographs, the survey report, and other pertinent information. Thus, these engineers are provided with an integrated and complete set of information for design of the highway. By using these sources the design engineers are able to determine each possible centerline, to measure the horizontal coordinates of the centerline, to calculate the related highway geometrics and the centerline description, and to plot it on the maps. Then, using the typical design cross sections and measured profile, the centerline design is completed as required. This procedure makes it possible to investigate and compare each feasible location for the centerline and to confirm its suitability and select the best.

Once the centerline has been designed, the design engineer forwards its computed description and plane coordinates to the photogrammetric engineer, who, using his original photogrammetrically compiled manuscripts, accurately plots the centerline, places the same large-scale photography back into the photogrammetric instruments and measures the profile and cross sections. Thus the necessity of substantiating the findings of the design engineer with a ground survey of the centerline, or related lines, has been completely eliminated.

It would be to the advantage of the project if the photogrammetric engineer while doing the large-scale mapping, on completion of such work with each stereoscopic model, could measure cross sections within the area of the model in relation to any baseline as defined in the plane coordinate system. The design engineer would then receive the large-scale detail maps and cross sections of his area of interest before starting the design work. Using the electronic computer and the DTM approach, he could obtain cross sections, profiles, and grading quantities for each possible alignment by defining the plane coordinates of the control points and feeding them to the computer along with the DTM for the particular route band of topography under consideration and the required computer programs. Work in this stage results in a designed location for the highway and detailed construction plans.

STAGE IV—LOCATION SURVEY AND CONSTRUCTION

The construction engineer is interested in physically constructing the highway according to the construction plans, and in determining the quantities of material required to do the work.

Hence, it is only at this stage that a survey party needs to physically establish the centerline and related lines on the ground. To facilitate this location survey, the construction engineer can establish the position of any point or line on the ground by trisecting, using accurate theodolites on previously placed station marker monuments for which the plane coordinates were determined in Stage III. This plane coordinate approach to surveying simplifies the location and construction staking, and is indispensable when it comes to staking complex interchanges and modern highways. Computer programs give the horizontal angles directly to each survey instrument, thus minimizing chances for human error and the accumulation of errors throughout any one project.

The construction engineer utilizes the cross sections measured with the precision stereoscopic instruments during Stage III. It would be desirable if the same DTM as described in Stage III was used for this phase. The construction engineer would simply define the reference baseline in horizontal X and Y coordinates, a line which could be conveniently occupied in the field. Cross sections would then be obtained by using the coordinates of the baseline, the DTM information, and the appropriate programs in the computer.

PHOTOGRAMMETRIC PROCEDURES

The Department of Highways, Ontario, has four KPP-3 Kelsh stereoscopic plotters, two of which are equipped with coordinatographs and electronic digitizing equipment for measuring the X, Y, and Z coordinates within each stereoscopic model. These units are utilized for aerial triangulation and for measuring profile and cross sections.

Aerial Triangulation

All basic horizontal ground control is measured with electronic distance measuring instruments and targeted before photography is taken. All stereoscopic models are bridged for establishing supplemental horizontal control. The photographic diapositives are prepared for aerial triangulation with the Zeiss Snap Markers. The stero-scopic model is placed into the Kelsh instrument and inner and relative orientations are made; the model is approximately leveled onto detail within the stereoscopic model or onto available vertical control. The model coordinates of control points and pass points are measured and automatically recorded onto computer cards, with each model in the strip being processed similarly and independently; the model computer cards are processed by electronic computation. (Our computer program performs a linear conformal transformation, with a least squares solution between successive models of the strip, and a linear conformal transformation with a least squares fit of the strip coordinates to the ground coordinates.)

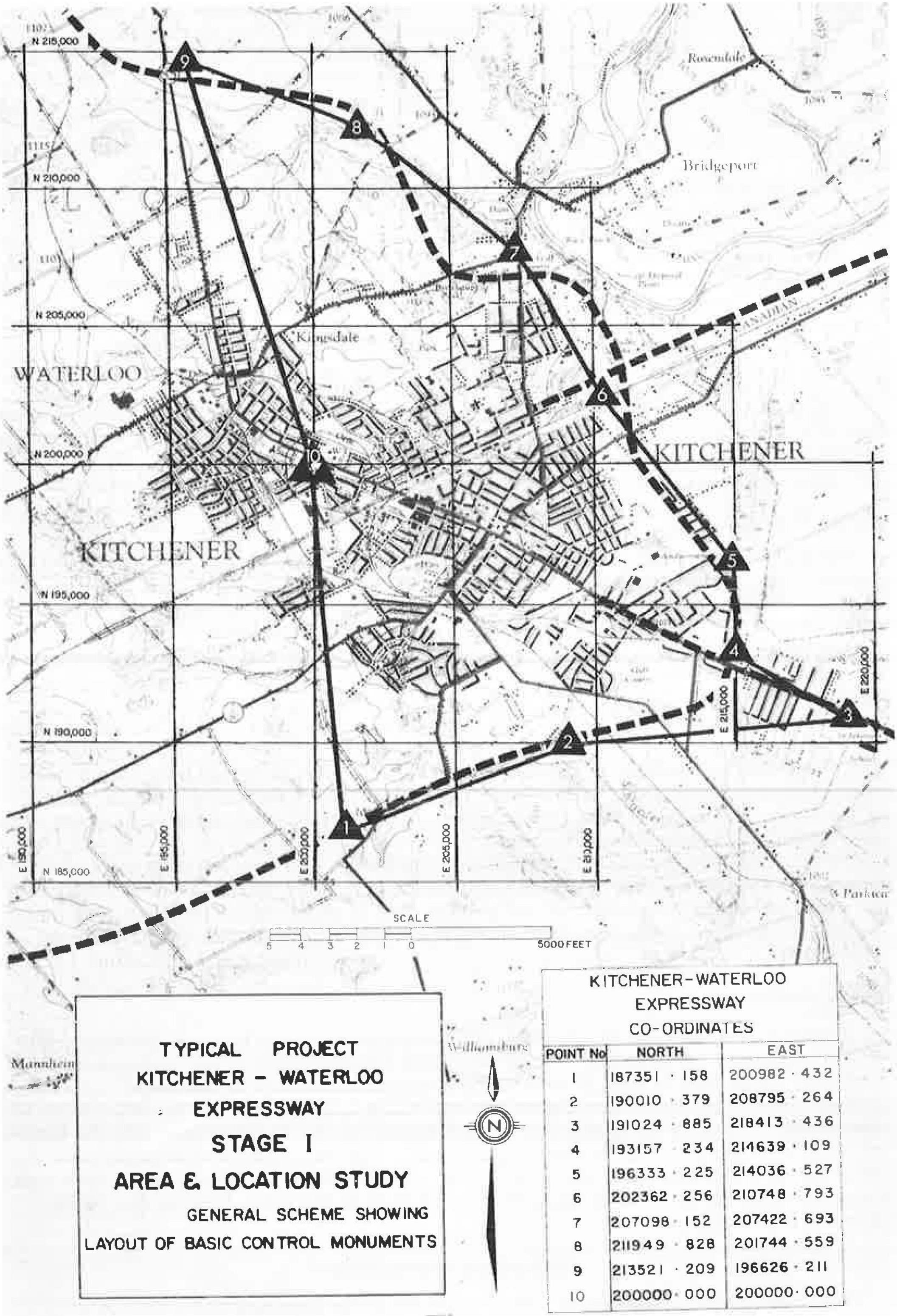
From a highway engineering production standpoint, this procedure is quite ideal. Our experience on all projects shows that the density of horizontal control required for other phases of the project is far greater than is required for the photogrammetric method procedures, indicating that more sophisticated procedures appear to be unwarranted.

Cross Section Measuring

Having established the location for the centerline from the large-scale maps, the design engineers compute and furnish its X and Y coordinates to the photogrammetric engineer. This line is then plotted on the original manuscript of the maps; the original photographic diapositives are placed into the Kelsh instruments and cross sections are measured. Naturally no centerline targets appear on the diapositives, only the targets of basic control points and marked pass points. Our Department is working toward adopting the DTM approach which, it is felt, will greatly facilitate cross section measuring procedures, permitting such work to be done at the same time as the initial large-scale mapping.

A TYPICAL PROJECT

The Department of Highways, Ontario, is using the approach described on several of its major projects. A 14.8-mile controlled-access facility going into construction



KITCHENER-WATERLOO EXPRESSWAY CO-ORDINATES

POINT No	NORTH	EAST
1	187351 · 158	200982 · 432
2	190010 · 379	208795 · 264
3	191024 · 885	218413 · 436
4	193157 · 234	214639 · 109
5	196333 · 225	214036 · 527
6	202362 · 256	210748 · 793
7	207098 · 152	207422 · 693
8	211949 · 828	201744 · 559
9	213521 · 209	196626 · 211
10	200000 · 000	200000 · 000

Figure 1.

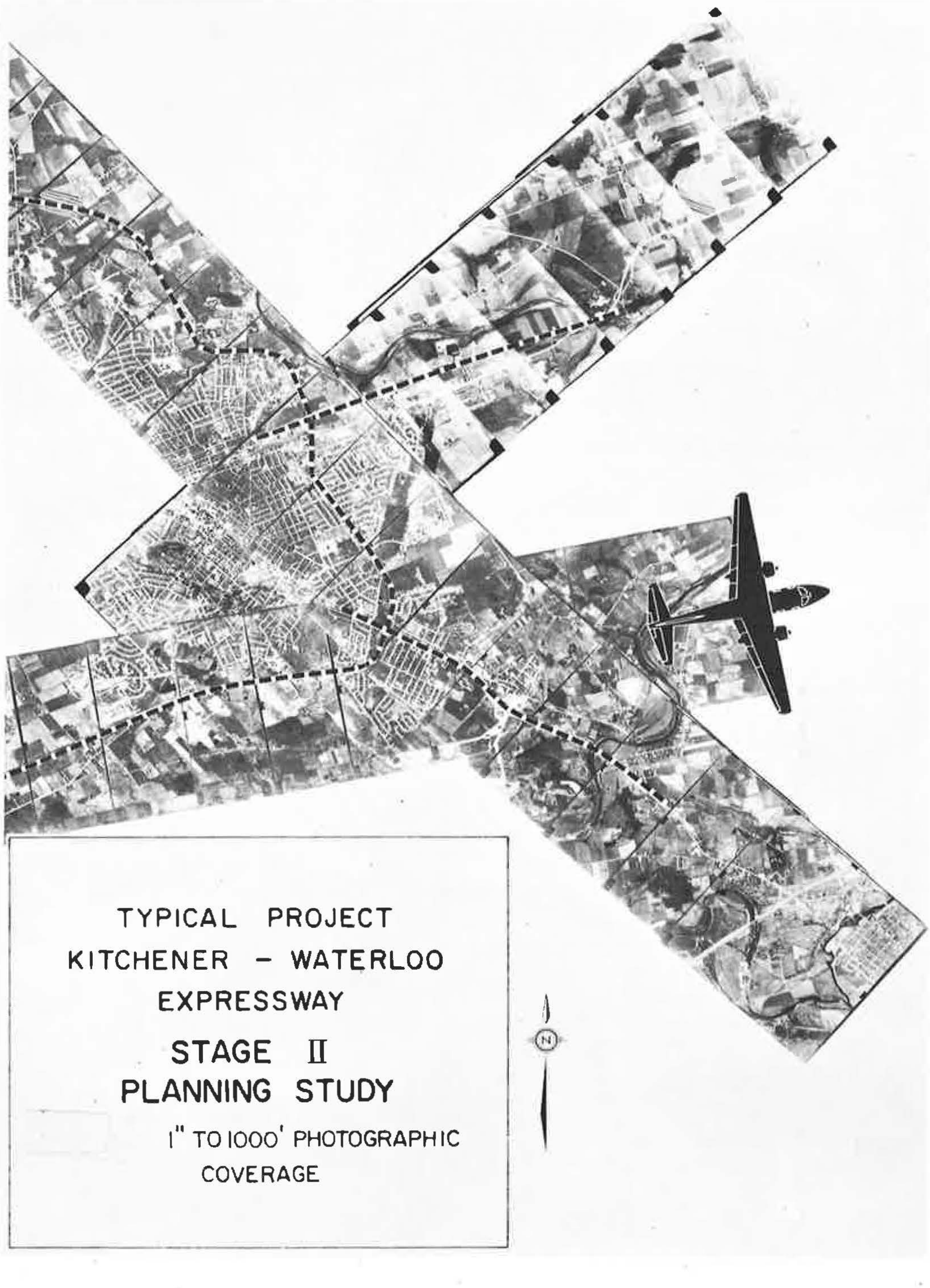

TYPICAL PROJECT
KITCHENER - WATERLOO
EXPRESSWAY
STAGE II
PLANNING STUDY
1" TO 1000' PHOTOGRAPHIC
COVERAGE
N

Figure 2.


TYPICAL PROJECT
KITCHENER - WATERLOO
EXPRESSWAY
STAGE II
PLANNING STUDY
1" TO 200' PLAN PRODUCED
PHOTOGRAMMETRICALLY SHOWING
PLANNING SCHEME & HORIZONTAL
CONTROL DENSITY FOR DESIGN
PURPOSES
SCALE
800 FEET
N
211,000 E
211,800 E
212,600 E
213,400 E
214,200 E
215,000 E
194,400 N
193,600 N
192,800 N
192,000 N
191,200 N
190,400 N
189,600 N
188,800 N
188,000 N
300+00
290+00
280+00
270+00
CO-ORDINATED POINT
NORTH
EAST
Pt. HS 16
190889·7
214341·4

Figure 3.


TYPICAL PROJECT
KITCHENER - WATERLOO
EXPRESSWAY
STAGE III
DESIGN
1" TO 200' PHOTOGRAPHIC
COVERAGE
N

Figure 4.

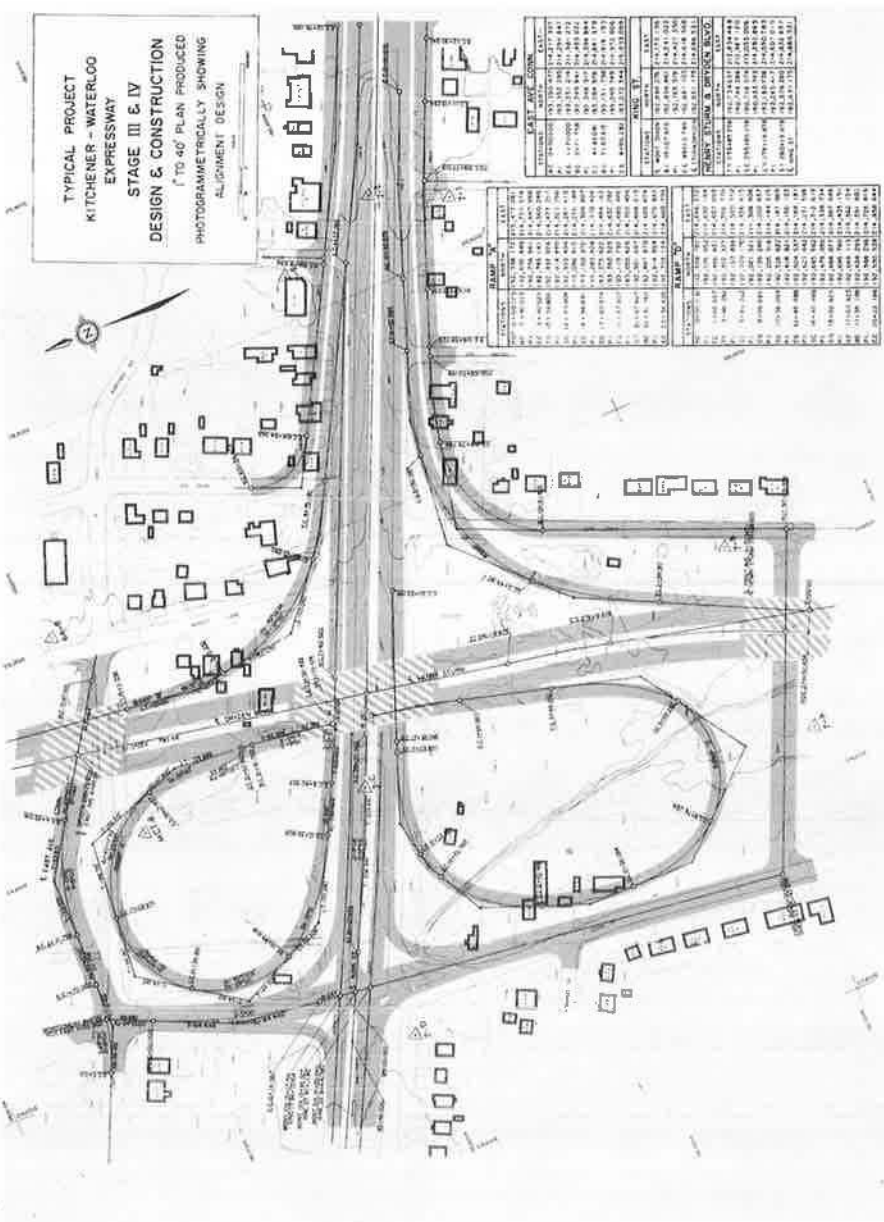

TYPICAL PROJECT
KITCHENER - WATERLOO
EXPRESSWAY
STAGE III & IV
DESIGN & CONSTRUCTION
1" TO 40' PLAN PRODUCED
PHOTOGRAMMETRICALLY SHOWING
ALIGNMENT DESIGN
RAMP "A"
RAMP "D"
EAST AVE CONN.
KING ST.
HENRY STURM & DRYDEN BLVD.

Figure 5.

this year in the area of the twin cities of Kitchener-Waterloo, Ontario, presents a good workable example (Fig. 1). Because this project had progressed into the preliminary survey stage before the 200 ft per in. topographic maps had been compiled photogrammetrically, such maps were not used exclusively during this phase. A portion of the project was mapped photogrammetrically as well as by ground survey, and a comparison proved the photogrammetric approach to be far more advantageous.

Control points marked by monuments on a plane coordinate system were established every 1 to 1 ½ miles along the proposed route corridor. This control was measured with a Tellurometer and targets were placed on the points before the photography was taken. Figure 2 shows the photographic coverage detained at 1600 ft per in.

Standard photogrammetric procedures of aerial triangulation and stereoscopic plotting were used to compile topographic maps at the usual scale of 200 ft per in. with contours at 5-ft intervals (Fig. 3). After the initial preliminary survey had been made and centerline location designed, the density of basic control was increased with a Geodimeter. Four-foot iron bars or plugs were set every 500 to 1,100 ft along the route corridor outside the probable area of construction and at an increased density in all intersection areas.

Precise leveling was performed to measure the elevation of 70 monuments throughout the length of the project. Basic horizontal and vertical control points to be used for subsequent photogrammetric work were targeted before the photography was taken. The targets used were either painted marks on the edge of the existing pavement or 2-ft-square pieces of tar paper with a distinguishing shape silk-screened onto them in yellow paint. These targets are very suitable because they are small, economical, have built-in contrast and provide a man-made shape as the photographic image.

The aerial photography was taken at the photographic scale of 200 ft per in. (Fig. 4). Aerial triangulation was done to establish supplemental control and 40 ft per in. topographic maps with contours on a 2-ft interval were compiled (Fig. 5). Special sepia paper reproductions of the original map manuscripts were supplied to all interested parties as soon as they were completed and edited by the stereoscopic plotting section. This procedure permitted the various operations of soil investigation, utility relocation, municipal survey, land (property) survey, bridge and railway design, and highway design to proceed without the two-month time lag required to field check and draft for reproduction and use the 1:480 scale maps.

The highway design engineers use these maps to design the centerline by considering any number of location possibilities, measuring the coordinates of the designed centerline on the maps, adjusting these coordinates slightly to facilitate future field staking, and calculating all route geometrics and the centerline description. The plane coordinates of the centerline are furnished to the Photogrammetry Division, the centerline plotted on the original manuscripts, the original diapositives placed into the Kelsh instrument, and the cross sections measured in the usual manner. The cross sections are used initially for accomplishing the design and later for staking the highway for construction. The construction plans are used by the design engineer for contract preparation, and are photographically reproduced and used as removal plans, paving and alignment plans, grading and drainage plans, and detour plans.

The centerline of the designed highway has not been occupied and will not be surveyed until the construction contractor occupies the basic control points and trisects to physically establish centerline stations for construction purposes. The design engineer has done only a normal amount of field surveying to verify to his own satisfaction certain design control measurements on the ground. Only a token number of the cross sections have been field edited and found to be well within requirements of both design and construction.

CONCLUSIONS

The conclusions are self-evident:

1. The photogrammetric method is capable of providing the various highway engineers with integrated and complete information, enabling them to consider all surface qualitative information and quantitative data in one clear pattern.

2. The system allows the highway engineers to function quickly, efficiently, economically, independently (to a large extent), and with a minimum duplication of surveying, at the same time ensuring an integration of all phases of the project.