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Foreword

Aerial surveys are the actual taking and use of aerial photographs to obtain needed data and to illustrate problems. Previously, papers presented at meetings of the Highway Research Board which were sponsored by the Photogrammetry and Aerial Surveys Committee pertained principally to the development and application of aerial surveys in highway location and design. There are many other uses of aerial surveys in highway engineering. Three different and additional aspects are included in the papers comprising this Research Record.

Among the significant problems confronting highway engineers are those associated with traffic, comprised principally of three interrelated factors—time, space, and number of vehicles. Upon examination of aerial photographs, certain aspects of such factors, and the temporary and seemingly permanent causes of traffic movement difficulties on streets, highways, and freeways, are revealed. Five of the seven papers in this Research Record are informative regarding ways in which aerial surveys were used effectively in ascertaining traffic data useful in solving many of the problems arising daily (often hourly) from the interaffecting physical characteristics of each motor way and its connecting facilities, various intensities and speeds of vehicles, and desires of drivers. Significant principles and procedures employed with indications of future possibilities of aerial surveys are given. Many valuable data were obtained, which otherwise would be costly and difficult, if not impossible, to acquire. Unique data presentation techniques are employed.

Among the topics included in the papers are: (a) ascertaining urban growth and determining traffic generation potential of various types and intensities of land uses; (b) studying traffic movements under various conditions; (c) making inventory surveys of freeways; (d) combining the use of photographic interpretation and photogrammetry to ascertain geologic characteristics and formations and to compile maps of the formations for highway location and design purposes; and (e) using precision double-projection instruments for photogrammetric bridging with strips of aerial photographs to establish supplemental control for use in photogrammetrically compiling large scale topographic maps for highway design purposes.

The value of aerial photographs of urban areas taken periodically each 5 to 10 years and used to determine the growth pattern, rate of growth, and changes in land use is well demonstrated in the first paper; also, how traffic generation potentialities of growth and changes can be anticipated.

The second paper reports on the ease with which inventories were obtained of freeways, including the identification of accident-prone places and conditions, vehicle movement paths, and situations where traffic signs were not serving well.

The next three papers discuss various ways in which aerial photographs were successfully used in making traffic surveys. Aerial photographs reveal causes of traffic problems and their consequences. Several separate sets of aerial photographs sequentially taken along a highway segment or of an interconnecting highway network during periods of various intensities of traffic contain a composite record from which the number of vehicles per hour and their speed, can be determined. In addition, traffic demand; traffic congestion by place, extent, and duration; and traffic bottlenecks were readily revealed upon examination of the photographs.

The sixth paper is a comprehensive and informative report regarding research undertaken and results accomplished in use of aerial surveys to ascertain and to map geologic formations. The practicability and benefits of combining photographic interpretation and precision photogrammetry are well demonstrated.

The last paper contains a detailed explanation of initial work done in bridging a number of stereoscopic models using double-projection photogrammetric instruments to establish supplemental control for absolute orientation of the stereoscopic models to compile large scale topographic maps. Techniques employed, results attained, and practicabilities and cautions are given.

In summary, these seven papers constitute a valuable contribution to research records and point the way to greater use of and benefits from aerial surveys in several phases of highway engineering: urban growth and land use changes, highway inventories, traffic surveys, geologic determinations and mapping, and establishment of supplemental control by photogrammetric bridging techniques.

William T. Pryor, Secretary
Committee on Photogrammetry
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Contents

Determining Urban Growth and Change from Aerial Photograph Comparisons

BRUCE E. HOWLETT, Land Planning Consultant, Puget Sound Regional Transportation Study

• THE UTILITY of employing aerial photograph comparisons as a principal means for determining changes in the location and quantity of urban land uses over a period of years is discussed in this paper. It was prepared as an outgrowth of studies undertaken by the Puget Sound Regional Transportation Study as preparation for a regional land use forecast. The purpose is to examine the quantitative and structural growth of land uses over a period of time with the intent of ascertaining whether any persistent patterns occur which could be used in predicting the shape of the future growth of a metropolitan region. Aerial photographs, together with other geographic information sources, form a basis for the determination of these land use patterns.

PUGET SOUND REGIONAL TRANSPORTATION STUDY

The Puget Sound Regional Transportation Study (PSRTS) is a joint effort of the Puget Sound Governmental Conference and the Washington State Highway Commission, in cooperation with the U. S. Housing and Home Finance Agency, the U. S. Department of Commerce (Bureau of Public Roads), and the Washington State Department of Commerce and Economic Development. The Puget Sound Governmental Conference was the originator of the project and represents the cities of Bremerton, Everett, Seattle, and Tacoma, and the counties of King, Kitsap, Pierce, and Snohomish.

The objective of PSRTS is to formulate a transportation plan as part of a regional development plan to serve twice today's population. The area of study is the most developed 1,700-sq mi urbanized portion of the Pacific Northwest, with a present population of 1.5 million. This objective, as well as the extent and content PSRTS, and a fixed budget limit were all defined in the Prospectus (1) prepared by a technical committee prior to the beginning of the study.

Land use information is essential to a transportation study for two reasons: (a) because the number of trips which leave or arrive at a place within an urban complex is closely linked to the kind of land use found there, and (b) because the travel patterns within the study area depend on the desires of people to travel from one kind of land use area to another for a particular purpose. If it is possible to predict the future location of different land use configurations in an area, it is then possible to estimate the number of trips which may be forthcoming from these areas, together with an estimate of their distribution to other areas. Such travel forecasts can tell where the transportation network will be overloaded much in advance of its actual occurrence and plans can be prepared to avoid such conditions.

URBAN GROWTH AND LAND USE FORECASTING

The Land Use Forecast

The land use forecast is the first of two primary activities undertaken by the Land Planning Division of PSRTS. The second is the preparation of a land use plan, not discussed as part of this paper.

A land use forecast is a relatively precise image of how land will be used in the future, based on the premise that present urban development trends will continue and

Paper sponsored by Committee on Photogrammetry and Aerial Surveys.

that land use controls will be much the same in the future as they are today. A land use plan, on the other hand, would be a consciously-directed arrangement of urban land uses designed to maximize a set of community goals. In this particular study, the object is to forecast the quantitative and locational structure of land uses in the Puget Sound region for 1985 in areas ranging from as small as four blocks in extent in a central business district (CBD) to as large as several square miles in outlying areas. The land use forecast is derived by integrating detailed analyses and forecasts of specific land uses with the findings from studies of other elements which are felt to influence the land use locational pattern. These other elements are direct influences on the ultimate distribution of specific land uses and are therefore considered as parameters, allowing much more precise specification of location. These studies are three in number:

1. A physical limitation study, depicting the location of areas of various degrees of slope and soil type which will restrict or influence the emerging pattern of urbanization.
2. A local plans and program study which evaluates all zoning, plans, and progress of planning agencies in terms of their record of effectiveness and dependability in determining land use locations and intensities.
3. A historical growth study in which the past evolution of urban growth patterns and specific land uses is determined. Location trends, quantities of land per capita and other indices are derived from this study which, if persistence is shown over a period of time, may aid in forecasting the structure of land use locations in the future.

Although these studies are considered to be very directly influential in land use allocations, others derived from sociological, demographic, economic, and political influences can also be undertaken. Population and economic base studies and projections were undertaken to provide bases for determining the total amount of land in different uses in the future regional area.

Historical Growth Study

The study of historical land use patterns is basically one of map research. In as clear and precise a manner as possible the uses of land in past periods must be identified from whatever sources are available, then entered and measured on maps of a suitable scale for specific dates in the past. Normally, it is impossible to obtain data for a specific date or even a specific year. In general, the researcher must be content to specify a period ranging from one to two years on each side of a target year, particularly for periods 30 to 40 years or more in the past. The degree of land use detail which is sought becomes more restricted the farther back in time the research goes and has a direct bearing on the precision of land use comparability and quantification over time.

AERIAL PHOTOGRAPHS AND HISTORICAL GROWTH

Sources of Information

Old maps are the first source of information, whether locally prepared or prepared by some Federal or State agency. Works Projects Administration maps are useful. Books, newspapers, and "old timers" are likely sources if the researcher knows just what to look for or what to ask about. Often these sources are resorted to in filling out data on an incomplete map. Old city directories are useful and the local library is often a fruitful source. Old photographs aid in identifying specific uses. Aerial photographs are valuable if they are available at scales sufficient for accurate interpretations of urban land uses through study of structural differences, ground markings, etc. They can be secured in some areas for periods dating back to the 1930's or before. Some oblique views can be found in some cities for periods before the turn of the century. These photographs, when compared to recent flights form a secure foundation for historical growth comparisons.

Available Aerial Photographs

A search for historical data in the Puget Sound region uncovered a complete set of aerial photographs which were flown over the most populous part of the area in 1936. These photographs were prepared as part of a county program and were available, if required, at a scale of 100 ft to 1 in. They formed a sound basis for comparison with the complete aerial photography coverage obtained by PSRTS for its own purposes in the summer of 1961. It was determined that the negatives were still in stock and prints could be obtained at any desired scale from the aerial survey company that had taken the aerial photographs in 1936.

A few prints of such photography were obtained for use in preparing this paper. The original prints, available in the vaults of the county which originally had the photography taken, were used in the actual preparation of historical data used by the Transportation Study.

Other aerial photography coverage was also available for various dates in the past and was utilized in preparing historical study data. The example presented here is one which depicts extraordinarily good coverage at a very satisfactory scale.

Comparison of 1936 and 1961 Photographs

The first photographic pair (Fig. 1) shows a suburban area of Seattle. The 1936 photograph (A) shows a major highway through the center. Two crossroads appear one at the top and one in the middle. By photographic interpretation, a few scattered commercial structures along the highway right-of-way, a railroad right-of-way, a school, the beginnings of residential development on a block pattern, and large areas of open land, some in orchards, some in small gardens, but mostly unused, can be identified. The accuracy of the interpretation can be increased by reference to old city directories, USGS topographic maps published on a quadrangle basis, when available, Sanborn maps, and old W. P. A. maps.

By 1961 (B), the area has shown substantial residential and commercial growth. The road pattern is the same although virtually all roads are paved. The area is about 100 percent developed. Commercial uses are strung out in profusion along the highway, and each of the crossroads has attracted a supermarket. The school to the left has expanded considerably, and a new site has been established at the lower middle right edge of the photograph. Land uses were first identified by photographic interpretation and then checked in the field as part of the basic land use inventory for PSRTS.

Figure 2 shows several different types of uses in the same general area. To the right in the older photograph (A) is a residential area. In the upper right corner it is fully developed, in the lower right, the streets and sidewalks are laid out but there is very little development. The middle right of the photograph contains a steep slope area, evident by the switchback road in the lower part of the photograph and the curving road in the upper portion. The mining of the bank seems to indicate a clay deposit used for brick production. A major road passes through the area with some scattered wholesale or industrial properties along each side. The residential area in the center, although somewhat scantily developed, is being invaded by industrial uses. Other industries appear on the upper left. A roundhouse is in the upper left corner. Again, exact uses can be determined from old directories if finer detail is required.

By 1961 (B), considerable infilling has occurred. The residential area is fully developed and the streets are paved. A power line cuts a swath through the residential area ending at a substation in the industrial district. The industrial area along the road has expanded and the intrusion into the residential area continued. In the area along the left part of the photograph considerable industrial growth is evident. A fully developed industrial district has emerged.

Figure 3 is included not so much to indicate the extent to which an area can change but to show the hazards possible in predicting land use patterns.

A study of this type is undertaken to formulate some indication of trends and persistent patterns of location found in each land use type. Essentially, this is the same as taking old aerial photographs and predicting the land use pattern seen on the new ones. Figure 3 shows an area in 1936 (A) laid out in city blocks but very sparsely

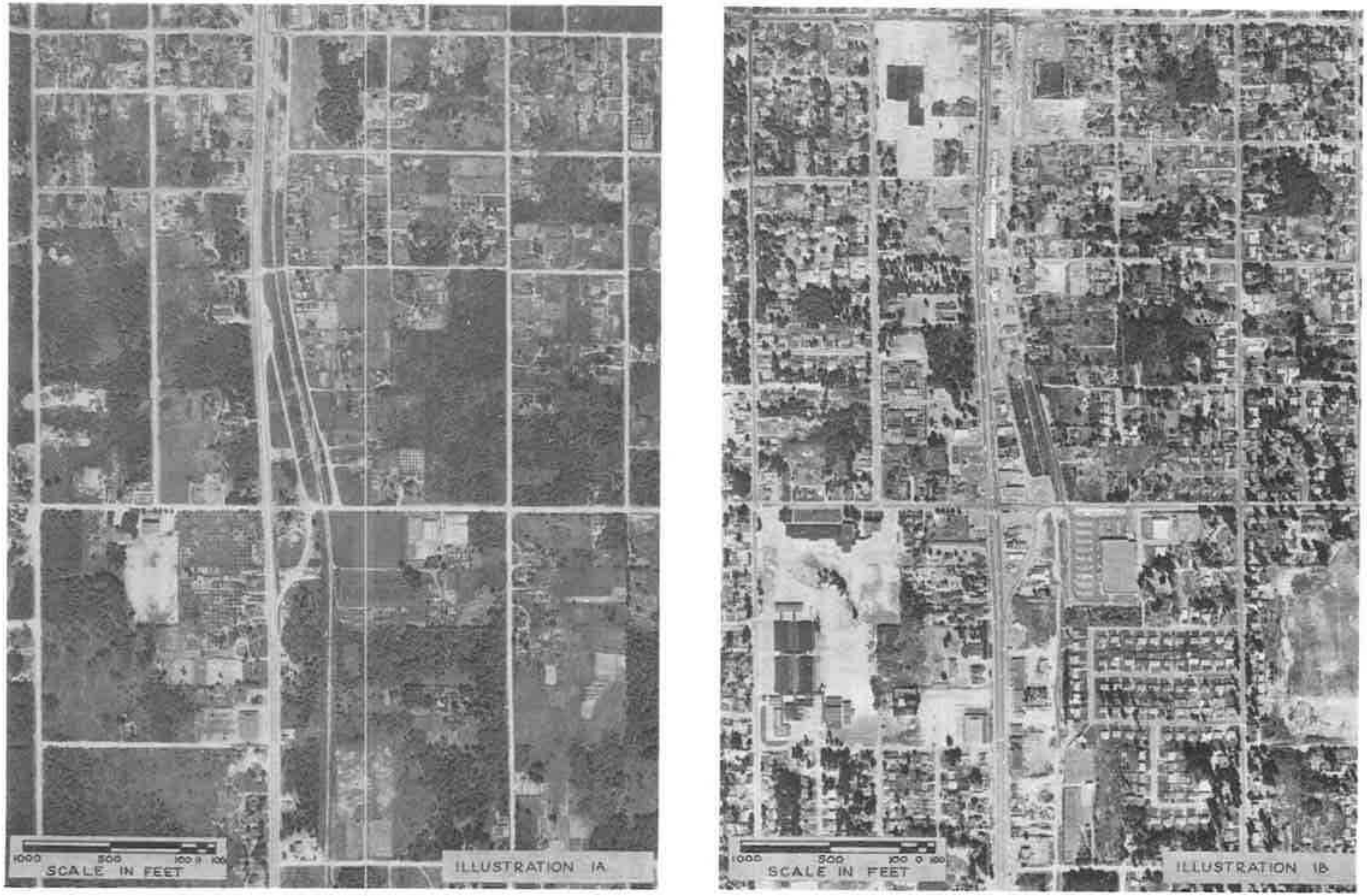

Figure 1. Photographic comparison: (A) 1936; (B) 1961.

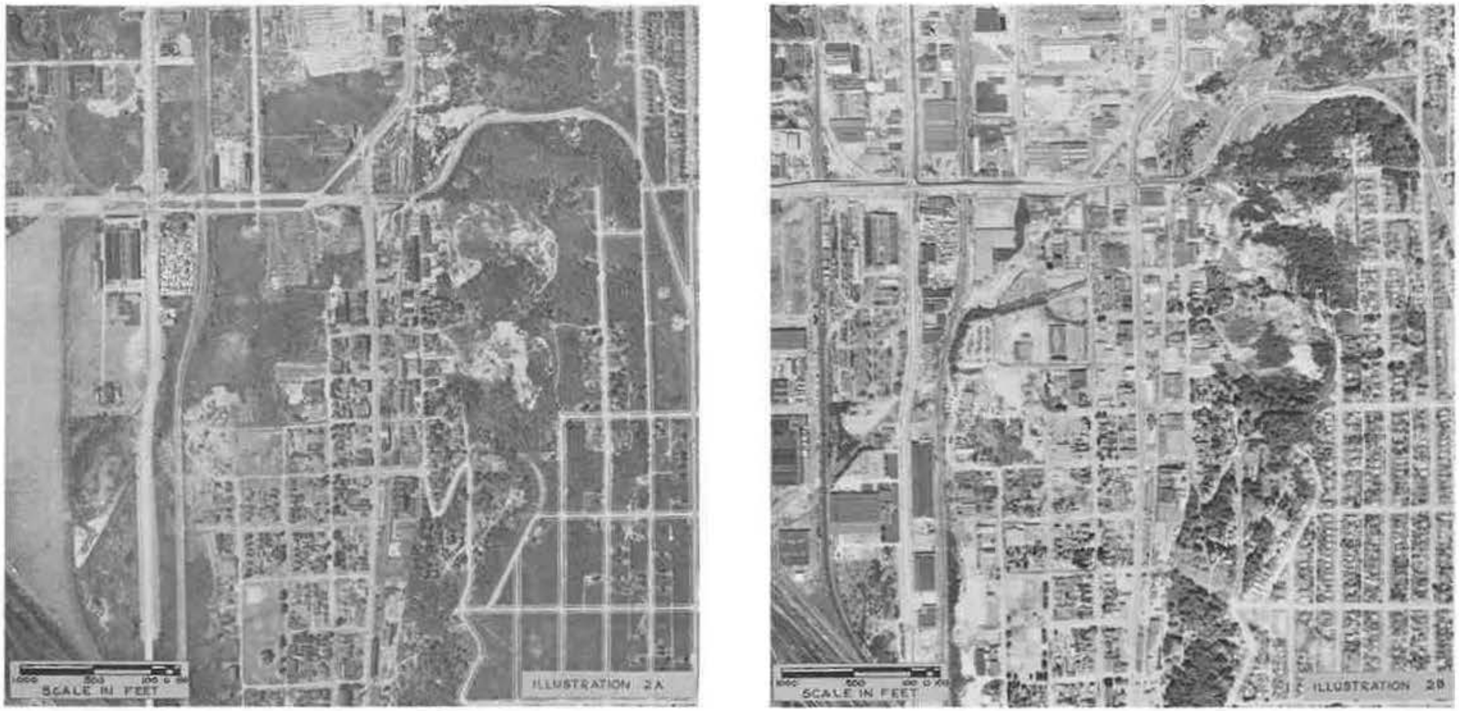

Figure 2. Photographic comparison: (A) 1936; (B) 1961.

Figure 3. Photographic comparison: (A) 1936; (B) 1961.

developed. There is a large block in the lower center of the photograph. By 1961 (B), this block had become the site of a shopping center, evident by the unified arrangement of the buildings and the large parking areas surrounding them. Trying to predict this type of land use at the time the old photograph was taken would probably have led to a wrong conclusion, because such shopping centers were completely unknown at that time. What new types of land development may occur 20 to 25 years from the present day are also unknown. It is assumed that for the most part existing patterns and types of development will persist, but as this example indicates, it is possible to err.

Figure 4 also shows the hazards of prediction. In this area some land has been created over the past 25 years. In the 1936 photograph (A), a dockside area covered partly with structures is shown. The central and upper left indicate a lumber mill. By 1962 (B), although the lumber mill remains the same, considerable increase in land use has occurred in other parts of the area. In addition, substantial quantities of new land have been created and structures are beginning to appear in these locations.

Figure 5 shows a pattern which has now become familiar, an extensive growth over an area which was largely undeveloped in 1936 (A). However, in the area in the lower right there is a crossroads clustering of stores. By 1961 (B), this complex has expanded considerably and ribbon growth extends along the main road to the north. This type of growth is reasonably easy to predict, and even the structure of retail store types found here can be predicted with satisfactory accuracy. The data obtained from analyses of changes revealed by these photographs are of considerable assistance in this task.

Although some commercial uses could not have been predicted as to location in 1936 (as indicated in the shopping center example), "strip" commercial development could likely have been successfully predicted as to location. The utility of a study of this kind is in determining how and where patterns do change. By further research, it is possible to determine why changes have occurred and whether further changes might occur in the future.

PREPARING ANALYSIS MAPS

Once land use data have been ascertained by interpretation of the aerial photographs, it must be transferred to maps for analysis of time trends.

Mapping by Decades

For analytical purposes, the 1936 photographic coverage in the Puget Sound region was checked against other data sources. It was determined that, in most cases, changes and increases in land use had been so slack after 1930 that these photographs could safely be interpreted as representing conditions quite close to 1930.

The techniques employed in interpreting land uses from aerial photographs were referred to previously. Historical uses can be interpreted directly from the photographs in generalized categories. More precise delineations are obtainable through supplementary means such as old city directories, old Sanborn or other maps, and similar sources. Unfortunately, in the Puget Sound region, aerial photographs were not available for all the decades studied or for the total area surveyed. Had they been more generally available, they would have been unsurpassed as a data source.

When interpretations are completed, they must be transferred to an analysis map of satisfactory scale. At PSRTS a scale 1 mi to 1 in. was used, and, although resorting to scales of ½ mi to 1 in. and larger will permit more precise mapping, the choice of scale depends directly on the accuracy and degree of detail obtained in the historical research. The more refined the detail (which must be consistent over general target dates), the larger the scale may be, and more land use categories can be shown.

One map is prepared for each decade (or for intermediate years, if desired) showing all the land uses in a color code system. Residential uses are shown in yellow (with shadings through brown to indicate duplex and apartment uses, if desired), commercial in red, industrial in purple, etc. (2). At PSRTS, only urban uses were interpreted and recorded, although open uses such as agriculture, timber, mines, quarries, and similar categories can be shown, if desired. Figure 6 shows the generalized result

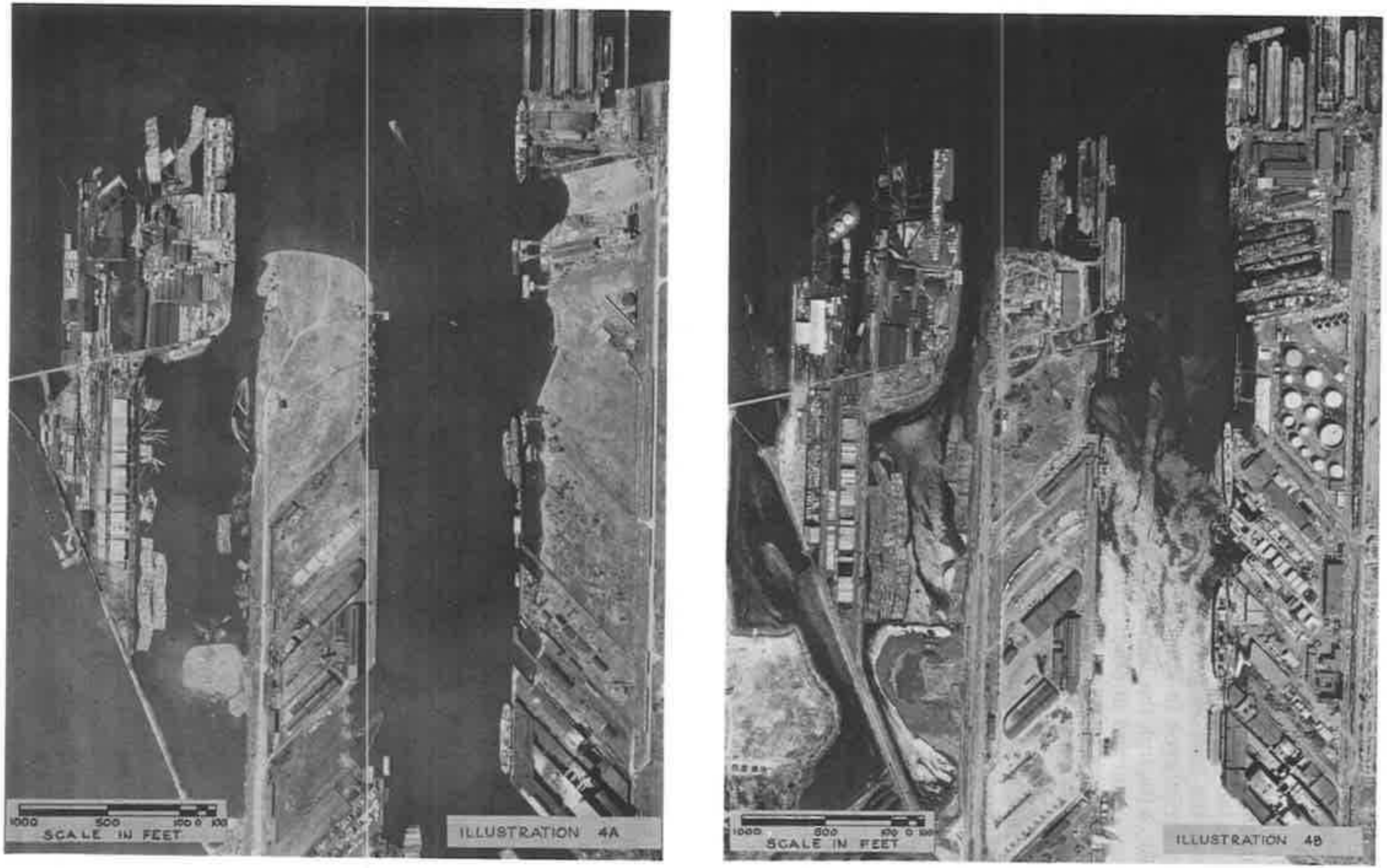

Figure 4. Photographic comparison: (A) 1936; (B) 1962.

Figure 5. Photographic comparison: (A) 1936; (B) 1961.

of interpreting the 1936 photograph (Fig. 2A) and the 1961 photograph (Fig. 2B) utilizing symbols rather than color.

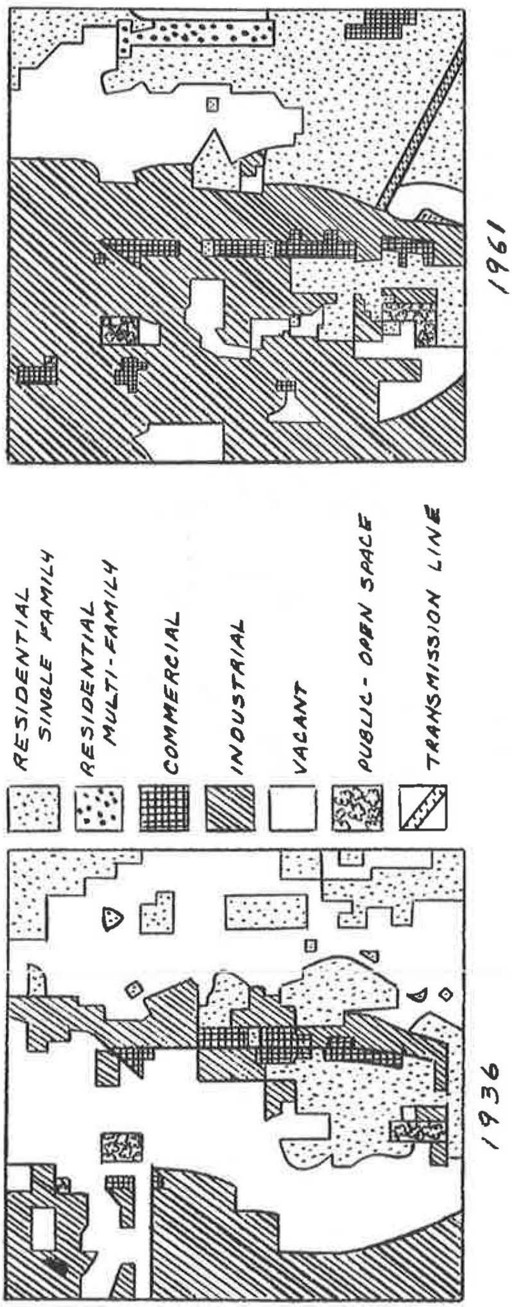

Figure 6. Land use comparison.

Total Urban Growth

The land use maps which have been prepared depict the total growth of the urban complex over a given period of time. If all the uses were colored black, urban growth would look something like a creeping ink spill when viewed decade by decade. An example of this is shown in Figure 7. The amount of land which has been urbanized is measured at this stage to provide a basis for correlation with other indices. Measurement can be made by conventional means such as a transparent overlay grid with standard units of area, or by means of a planimeter.

Separate Land Uses

Relying on the separate color designations for each type of land use, analytical maps which show the changing structure of distinct land use classes can be prepared. Utilizing a matte finish transparent overlay material, one sheet for each land use, a time series of changes can be shown by successively tracing the extent of the particular land use on the overlay, decade by decade. Figure 8 shows the growth of industrial land uses over a 40-yr period, and Figure 9 shows the growth pattern of commercial land for the same period.

Measurements of the amount of land in each category are also made from the overlay sheets for later correlation and are added together to check the measurements obtained in preparing the map of total urban growth.

HISTORICAL GROWTH ANALYSIS

Correlations with independent indices, analysis of locational trends, and determinations of the influence of physical and man-made features form the basis of the growth analysis.

Analysis of Total Urban Growth Map

After the map of total urban growth is completed and the areas measured for each decade, an analysis is undertaken to determine if there are any

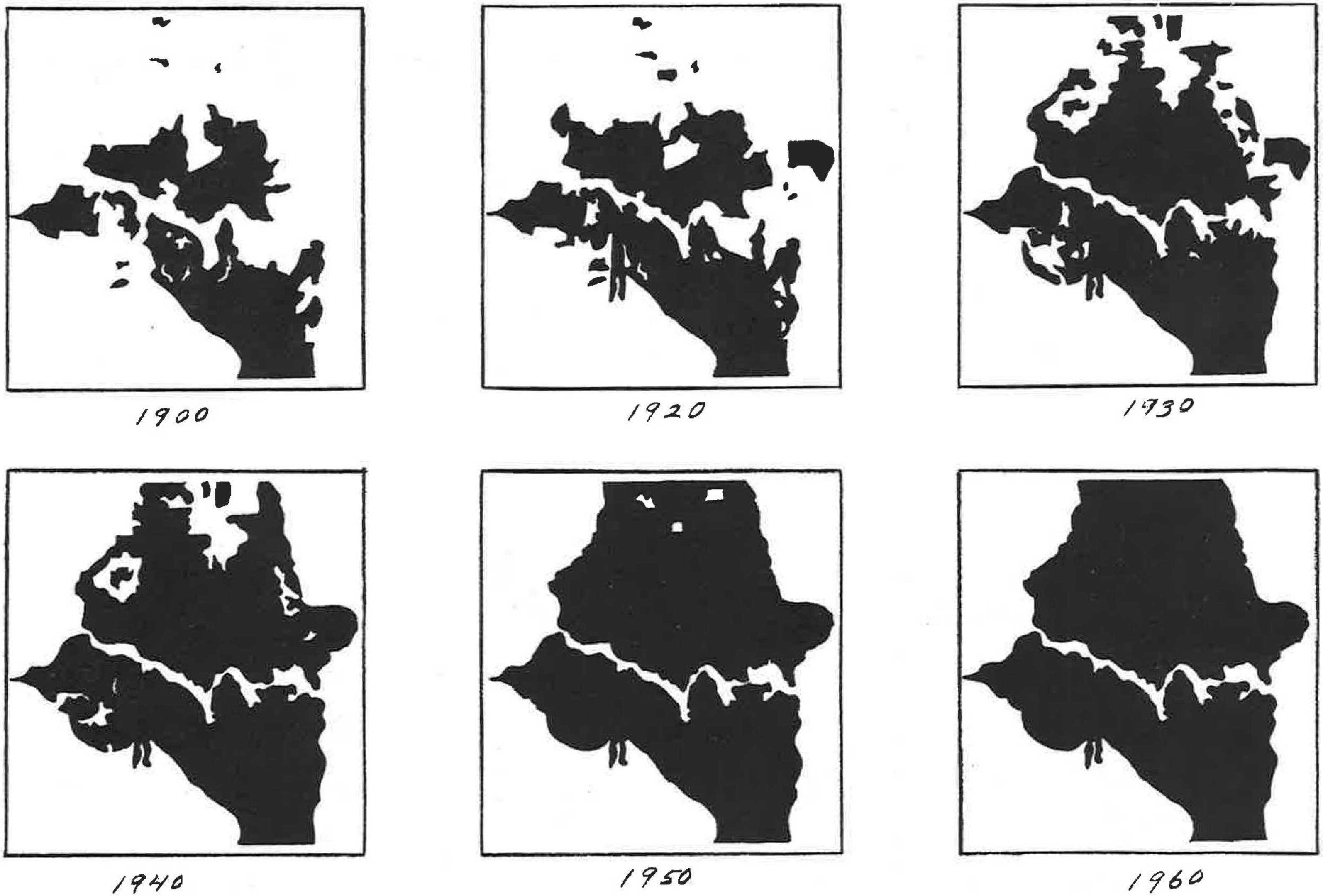

Figure 7. Total urban growth.

Figure 8. Industrial growth.

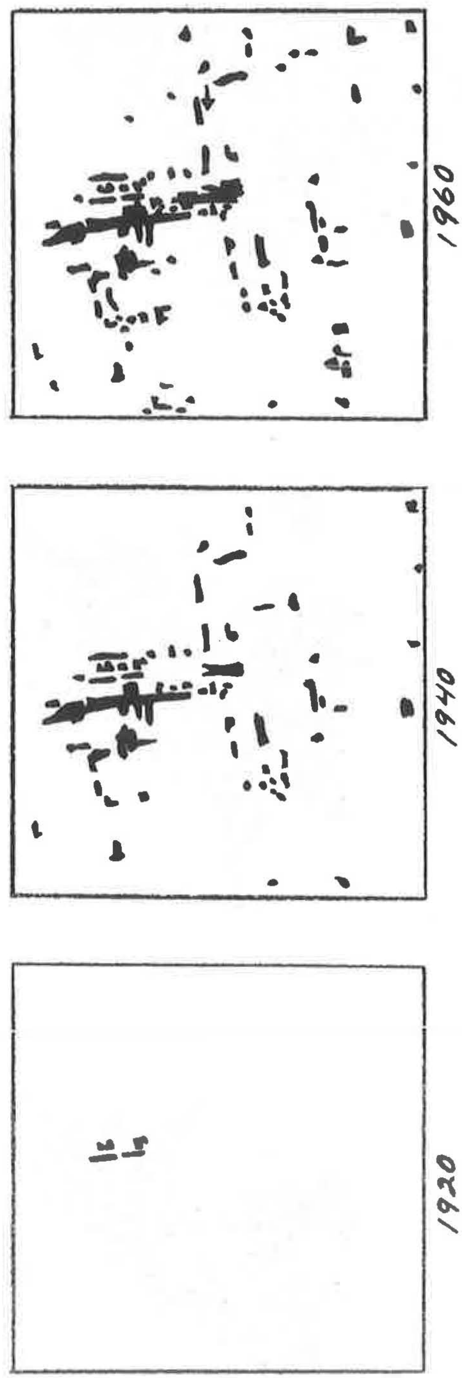

Figure 9. Commercial growth.

persistent trends. The total urban area measured by decades is first correlated with population by decades. If there is a long-term stability in the relationships obtained, there may be a valid basis for implying a persistence in the supply of urban land related to population.

Locational Patterns

A study of the locational pattern of urban growth is next undertaken. In this analysis the growth pattern is examined for persistence in directional trends. This can be done by selecting base lines running through the center of early settlements and measuring the quantities of growth in each direction by decade. The shape and structure of growth is also observed to determine if it has proceeded in an agglomerated or fragmented manner.

Influence of Physical Features

The influence of physical features is next considered in an attempt to understand whether they have a direct or indirect relationship to growth. Areas of steep topography, bogs, swamps, rocky areas, etc., are correlated with the growth pattern to determine if they have channeled, restrained, or otherwise influenced the emerging urban structure over a given period of time. If a physical barrier is at first seen to deter or channel the growth pattern and later to succumb to growth pressures, it may indicate that the potential value of the land had reached a point where some modification of the physical features became economically feasible. On the other hand, some features such as slide areas, extremely steep and rocky topography may never be overcome.

Influence of Man-Made Features

Man-made features are considered to determine if they also influence the pattern of growth. In this analysis, particular attention is focused on the provision and improvement of key roads or highways, the installation of bridges, ferries, and other factors related to the transportation pattern. In past decades, the influence of streetcar, interurban, and railroad service is usually very evident. In more recent times the provision of major high-speed arterial highways is usually influential in affecting the growth pattern.

Analysis of Separate Land Uses

The methods used in analyzing each separate land use are essentially the same as those for total urban growth. Close attention is paid to each distinct land use growth pattern and to the links with man-made features. Some uses are also highly sensitive to physical features. For example, industrial lands grow by agglomeration, adding to basic locations each decade with very few new sites being established over time. Industry is highly sensitive to slope and generally demands a complex of transportation facilities such as highway, rail, and water, although some more recent sites are not so dependent on rail. Retail-commercial areas, on the other hand, generally grow by fragmenting, the only key growth area in the past being the CBD (which is now declining). Commercial land is never very large in area, even new shopping centers being small in comparison with industrial lands. Orientation to the key modes of personal travel is the primary single link to man-made features. Relatively level land is required, but, because of the high value of a good commercial location (such as a major crossroad), physical impediments can be economically overcome. Figures 8 and 9 show the growth pattern of industrial and commercial lands in a part of the Puget Sound region.

Analytical Findings

In addition to the distributional pattern previously outlined, some more general relationships relate to land use quantities.

In the Puget Sound region, the historical growth study indicates a changing relationship between total urban land in use and population growth. Figure 10 shows this

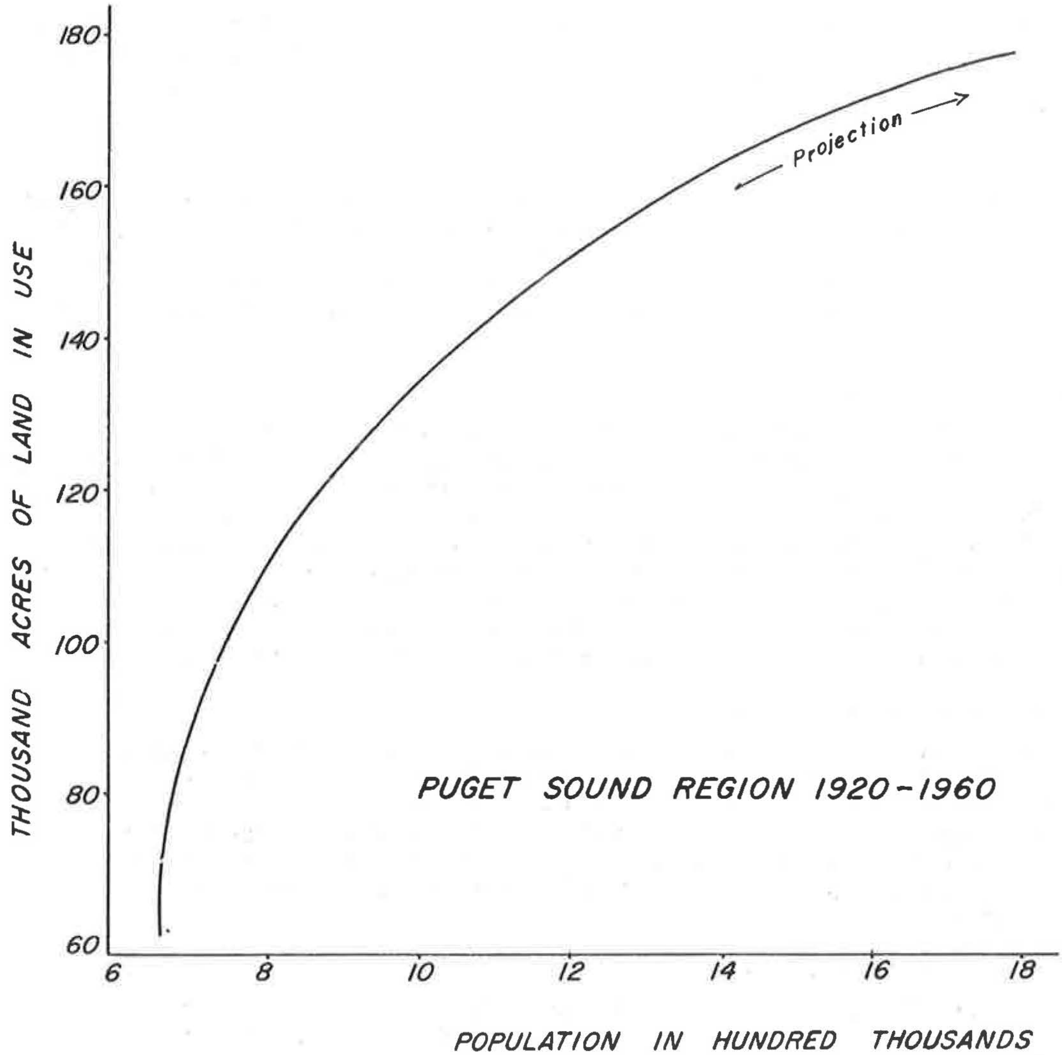

Figure 10. Land in urban use.

TABLE 1

URBAN LAND USES IN THE PUGET SOUND REGION, 1920-1960[1]

Land Use	Year				
	1920	1930	1940	1950	1960
Residential	1,712	1,950	2,243	2,286	2,320
Commercial	73	188	222	212	209
Industrial	446	603	700	567	533
Govt. and public	1,571	1,892	2,449	1,789	1,503
Public open space	261	588	807	624	601
Total	4,063	5,221	6,421	5,478	5,166

[1] Square feet of land per capita, including streets.

relationship over five census dates. It is evident that as population increases the amount of land in urban use increases at a decreasing rate. This is due in part to increases in density which occur as the population base expands.

Table 1 shows some of the results of the per capita analysis, indicating gross areas and including streets. Residential lands occupy the largest single use area with a per capita rate indicating a steady increase over time. Government and public lands are large space users primarily because of the relatively large number of military establishments occupying extensive land areas in the region. Variations in the rate of provision of government land and public open space depend largely on the policies and financial abilities of the different levels of government. Commercial uses occupy the smallest land area and appear to be relatively stable in rate when compared over time.

Reliability for Prediction

A historical growth analysis can provide a useful and reliable tool for land use predictions provided it must not be too detailed and is used in conjunction with a series of other analyses. Very recent trends in land use location are also valuable knowledge as a check on the persistence of past growth patterns.

The two components of the prediction are the amount of land and the location. Amounts are derived from the previously derived correlations. For example, if there is a clear, persistent relationship between amounts of land and population, then when a population forecast has been prepared, the amount of land to be urbanized can be predicted with general reliability. The location pattern can be determined by applying the findings of the location analysis to the predicted amounts of land. The impact of physical features and proposals for man-made changes (such as new freeways and bridges) must be noted and the potential influence in the future land use pattern assessed before the final structure can be determined.

Such general forecasts must be evaluated in terms of other analytical sources and adjustments made in allocations. In essence, they form the first approximation of the image of the future urban area—a general understanding of predominant growth movements and location patterns.

Aerial Photographs for Analysis and Prediction

The most important aspect of any historical analysis, on which a future forecast is based, is the reliability of the source data. Where aerial photographic coverage is available and adequate interpretations and measurements have been made, there is no question about the reliability of the data. In the case of the Puget Sound region, there was not sufficient aerial coverage, and it was necessary to resort to other sources of information. If there had been a regular program of aerial surveys, perhaps once every decade or preferably every half decade, a firmer basis for analysis of growth would have been obtained. In addition, forecasts of urban growth could have been entered on copies of the aerial photographs and checked for accuracy of prediction at a later date. This type of analysis emphasizes the need for periodic aerial surveys of the urban area. By making such periodic taking of suitable scale aerial photography a joint undertaking of several governmental agencies and by making it possible to obtain inexpensive copies, it should be possible to achieve this goal.

SUMMARY AND CONCLUSIONS

In this paper an exploration has been made of the utility of aerial photographic interpretation, measurement, and analysis as a means for determining urban growth and change in past periods. As a working tool for this purpose, aerial photography is unexcelled. When photographic interpretation is supplemented with secondary source data, the accuracy of urban land use interpretations can be as detailed as required and can accurately portray changing locational tendencies of land use over time. From land use measurements the quantitative aspects of land use changes can be determined and compared with changes in other key growth indices. Aerial photographs provide a firm basis for allocating land use forecasts and for checking their accuracy through periodic aerial resurveys. Essentially, this inventory and analysis adds an important function to the growing number of uses which are made of aerial photographs in examining the problems of contemporary urban society.

REFERENCES

1. Prospectus—Puget Sound Regional Transportation Study, approved by Technical Committee, 7/9/60 (Rev. 2/16/62).
2. Howlett, Bruce, "Land Use Handbook: A Guide to Undertaking Land Use Surveys." Northeastern Illinois Metropolitan Area Planning Commission, Chicago (1961).

California's Aerial Photography Inventory of Freeways

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In the Fall of 1960 and Spring of 1961 the Los Angeles area district and the San Francisco area district of the California Division of Highways were supplied with an aerial photographic inventory at a scale of 200 ft to 1 in. of most of the existing freeways in those areas. This initial inventory on 348 miles of freeways then existing in these two areas was of an experimental nature to determine whether large-scale aerial photography would be useful for traffic engineering applications such as studying accident prone locations, determining vehicle movement paths, and identifying signing problems.

• THE PHOTOGRAPHS in the Los Angeles area were taken between April 25 and May 12, 1960, and the material was accepted by the Division of Highways on August 18, 1960. The photographs in the San Francisco area were taken between December 22, 1960, and March 23, 1961, and accepted on May 18, 1961. In each case the photographs obtained were two sets of 9- by 18-in. contact prints on double-weight semi-matte paper at a nominal scale of 200 ft to 1 in., two sets of photography index maps, and all photographic negatives. Figure 1 is a typical contact print.

The work was done as two separate contracts. The contractors were supplied with 1:24,000 scale USGS topographic maps published on a quadrangle basis showing flight lines and areas to be photographed. The contracts required aerial vertical photography taken with a camera having a nominal focal length of 24 in. and a 9- by 18-in. negative size. The 18-in. axis oriented along the flight line gave ground area coverage 1,800 ft wide and 3,600 ft along the highway. Overlap in line of flight of at least 15 percent was specified.

At interchanges where ramp terminals were located more than 700 to 800 ft from the flight lines, additional photography coverage along the crossroads was obtained.

Total cost, excluding engineering by the Division of Highways, for the 348 miles photographed was \$7,130.40 or \$20.49 per mi.

The 9- by 18-in. aerial photographs have been enthusiastically accepted and are being used in a variety of ways. Uses include traffic engineering studies, research studies, design, planning, maintenance, project review, programming of improvements, and communications.

Traffic engineers use the photographs to study accident prone locations, to determine vehicle paths in relation to various geometric features, and to study signing problems. The photographs have also been used to determine the exact location to place pavement markings at interchanges and at intersection of ramps with surface streets, thus reducing the amount of field work normally required. Further, the photographs permit parking prohibition studies and studies regarding striping, signing, median barriers, illumination, and traffic control, with a minimum amount of field work and review. In addition, the photographs either eliminate or reduce the research ordinarily required into old plans, cross-sections, and records for accomplishing the previously mentioned traffic studies and for planning locations for traffic counting stations.

Paper sponsored by Committee on Photogrammetry and Aerial Surveys.

Figure 1. One inch equals 200 feet contact print.

The 9- by 18-in. contact prints have been reproduced in a variety of forms and scales to be used as exhibits in various reports. The untouched reproduction is used to show existing conditions. Proposed changes have been shown by delineating the recommended change in ink or colored pencil on the reproduced print.

The photographs contain sufficient details for making a convenient and accurate inventory of existing facilities and district planning departments have found them invaluable in planning and programming needed improvements. The photographs are more effective than maps in helping private citizens and technical staffs of local agencies identify properties and visualize improvements. The public in general, and especially property owners and developers seeking information, are favorably impressed by the fact that these photographs are available and by the efficient manner in which the engineer can communicate with the public when aided by the photographs. From the public relations standpoint, this is valuable.

The San Francisco area district office has utilized the photographs to produce base maps in planning an improvement to an existing freeway. This freeway is located in the City of San Jose on relatively level topography. A great deal of development has taken place along the right-of-way since the freeway was constructed so the initial construction plans of the highway were of little value for making a base map to plan the revisions required.

In cases such as this, it is customary to have topographic maps compiled photogrammetrically. Such mapping would have required several weeks. To expedite the preparation of the needed base maps and to reduce costs, the district prepared maps at a scale of 100 ft to 1 in. using the 200-ft to 1-in. scale photographs. Known distances between easily identified features along the freeway, such as ramp noses, bridges, and culverts, were used to determine the exact amount each photograph should be enlarged to produce the photographic base maps on sensitized polyester film. The amount of enlargement varied because photographic scale is a function of flight height, ground relief, and camera tilt. The resulting base maps, however, were reasonably close to the desired scale of 100 ft to 1 in. along the freeway, although scale in the transverse direction was not necessarily the same or uniform.

Although as the finished product was not as accurate as topographic maps which could have been compiled photogrammetrically, it was sufficiently accurate and detailed for the purpose of planning additional lanes required and for the preliminary design of modifications to the existing interchanges. The total time to produce the base maps (from photographs to the end product) was ten days.

The photographic inventory also has many useful applications in the maintenance field. The photographs help in analyzing drainage problems by locating existing facilities and spotting controls, and in determining corrective measures. They are used in discussing numerous field problems between office and field personnel. The aerial photographs eliminate need of specially prepared sketches to illustrate details during discussions.

In relinquishing old highways to local authorities and in drawing up maintenance agreements with local agencies, the photographs have been helpful in verifying details shown on plans or maps and in extending coverage beyond the limits of existing plans and maps. The photographs point up logical limits by showing such controls as fences, roads, curbs, drainage ways, landscaping limits, and other geographic, topographic, and physical features.

Another application by the maintenance department is in issuing permits for encroachments and for transit of extra-legal loads. The photographs expedite investigations and decision making on such applications by showing the degree and type of occupancy in the vicinity of the requested permit, and by showing other relevant factors such as driveways, traffic control devices, bridges, signs, and other restrictive controls.

Researchers conducting studies on speed, capacity, and safety have found the photographs useful. In a research project regarding wrong-way driving incidents on freeways, the aerial photographs were used in reconstructing the event and the path traversed by the vehicle to determine points of wrong-way entry.

Another application being investigated is the use of photographs to pinpoint the

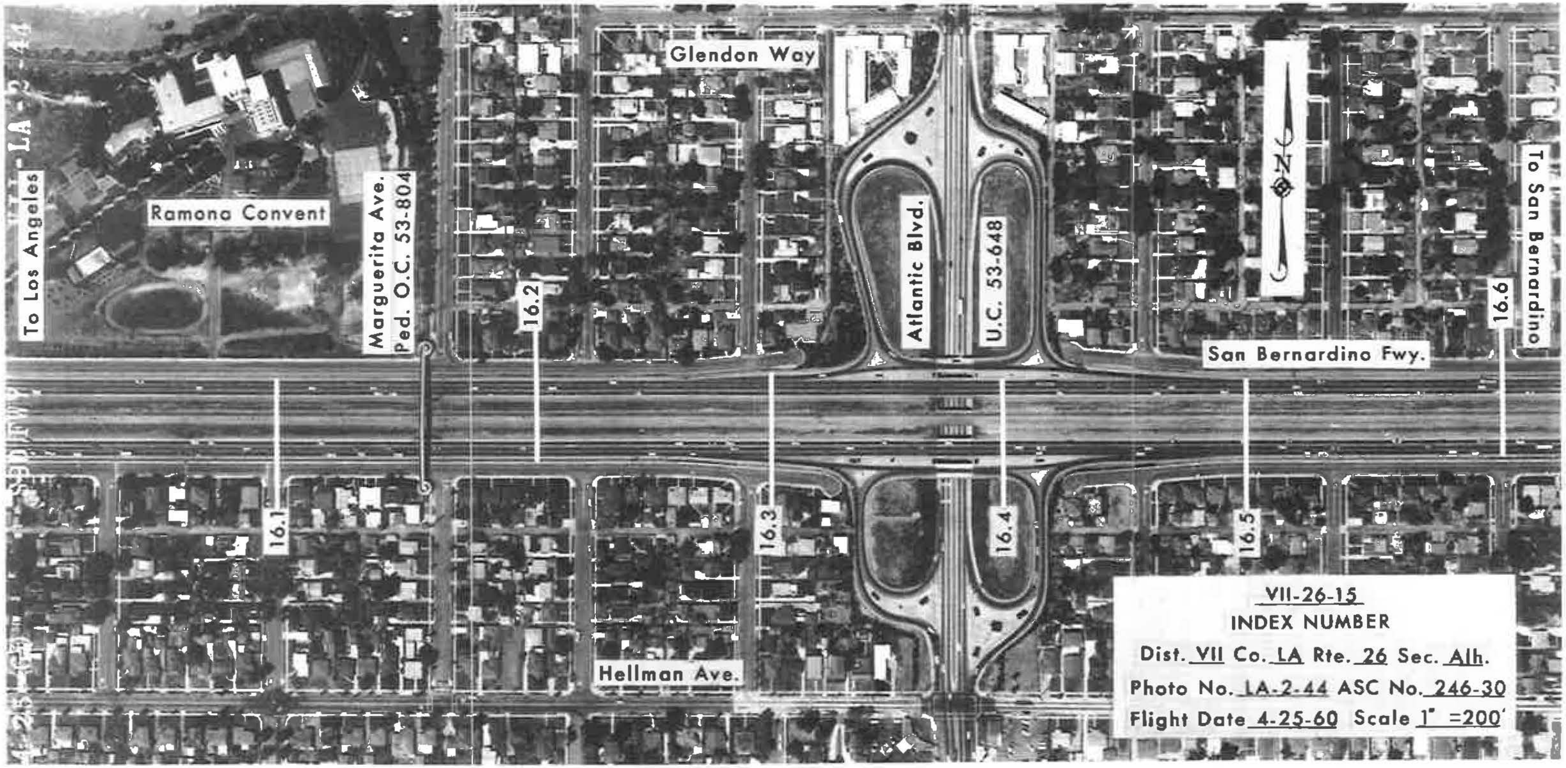

Figure 2. Multilith print showing mileposts and other data added for accident locating purposes.

location of individual accidents. Two highway sections totaling approximately 50 miles of Interstate 80 between San Francisco and Auburn are being used as a pilot study. (This is in conjunction with a major research project being conducted by several States in cooperation with the Bureau of Public Roads to relate accident rates to freeway geometric design details.) Multilith prints of the photographs are furnished to the California Highway Patrol. A copy is attached to each accident report by the officer after he indicates the location and the type of accident on the print. (Ozalid prints from screened film positives of the contact prints are also being used to outline and codify the various areas and interchange segments used in the study.)

The multilith prints were made from screen-process copy negatives of the semi-matte photograph originals. The prints are relatively inexpensive. In quantities of 100 or more the cost is approximately three cents each. Before making the multilith masters, identifying prominent landmarks, cross streets, milepost points, north arrows, and directions to nearest towns are added to the photographs (Fig. 2). The accident location can then be quickly obtained using a transparent variable overlay scale (Figs. 3 and 4). (An ordinary scale cannot be used since the photograph scale is not necessarily 200 ft to 1 in.; varies from photograph to photograph; and varies within a photograph due to camera tilt, ground slope, relief, etc.) This special scale should replace the longer, more costly method of computing distances between mileposts using distances measured between physical objects and recorded in the report by the officer. Thus far, however, sufficient experience has not been had with this application to determine if it will be as timesaving a device as expected. Also, there is evidence the patrolmen are having difficulty in site positioning the accidents accurately on the photographs.

There has been some demand by the users to increase the scale,

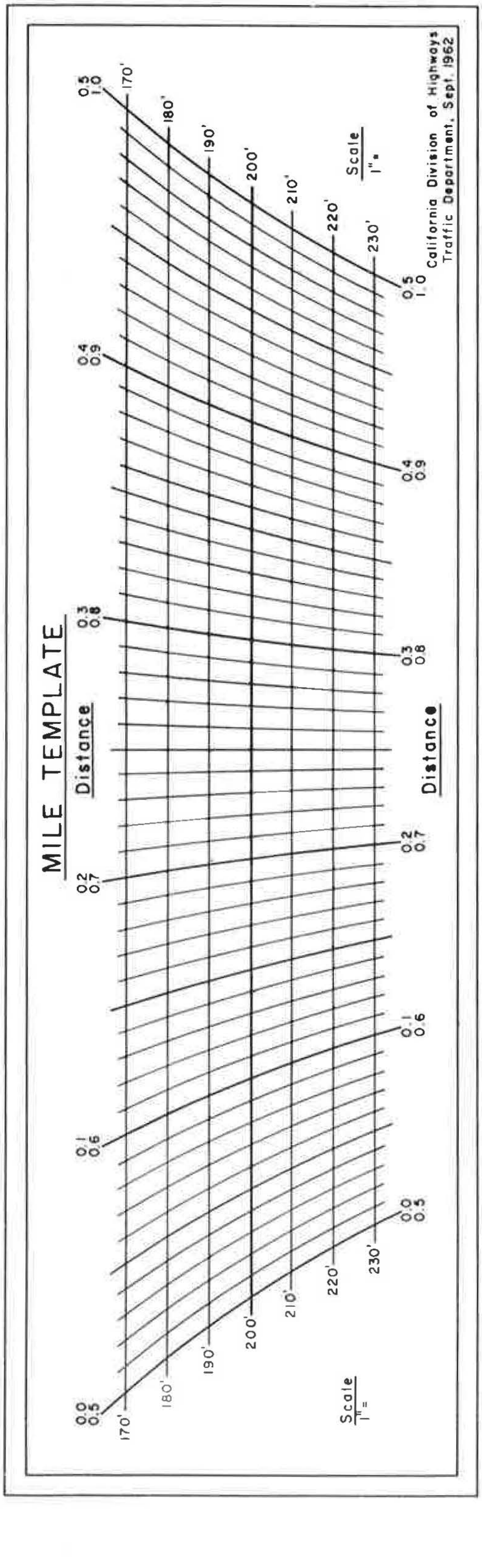

Figure 3. Transparent variable overlay scale.

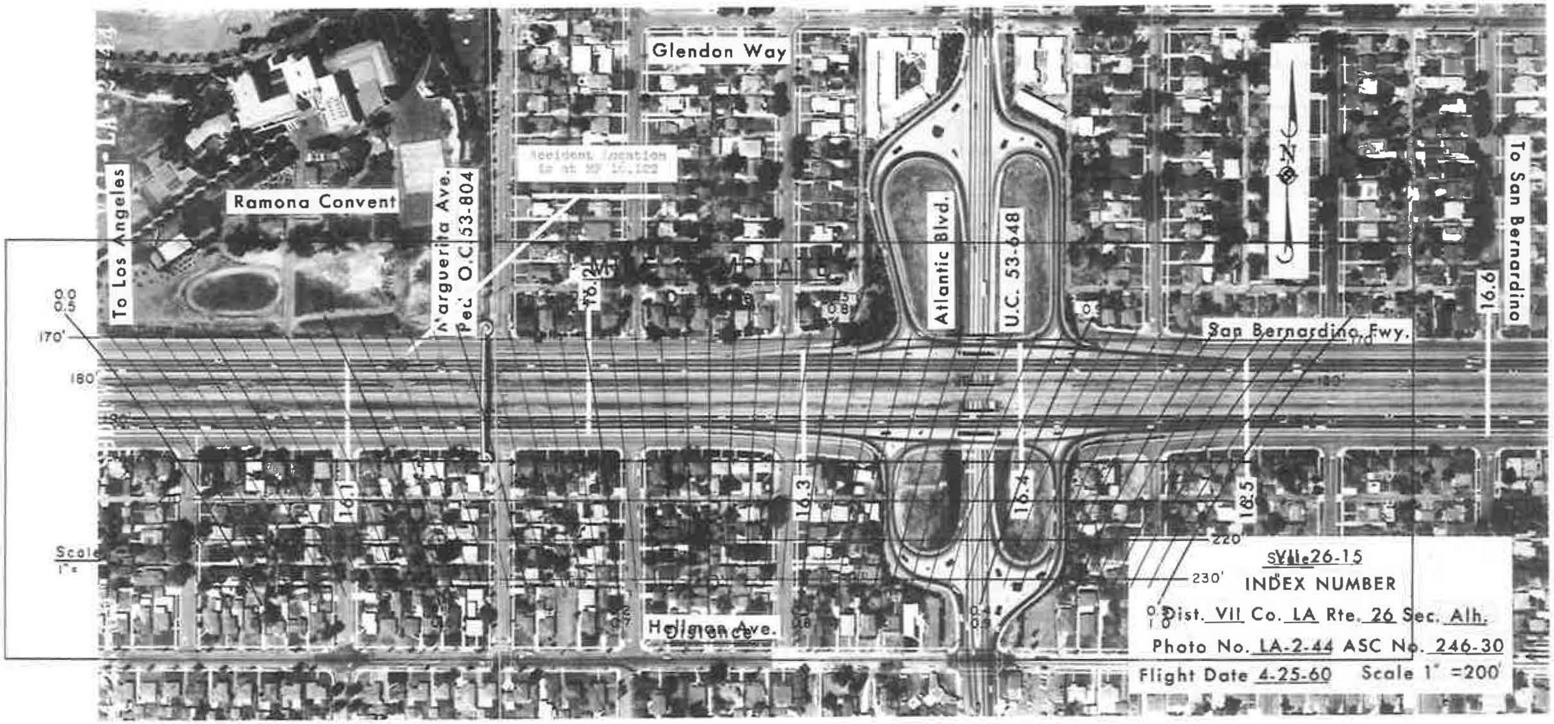

Figure 4. Determining accident locations with overlay scale.

obtain wider coverage, and extend coverage to all major highways (conventional highways as well as freeways). Increasing the scale to 100 ft per in. would increase costs approximately 75 percent. The cost of eliminating scale variations caused by ground relief and tilt of the photographs would be prohibitive. It is felt neither the larger scale nor a more accurate scale is necessary for the general applications made of these photographs.

Such photography coverage will be extended in the near future to all freeways in the State and this coverage will be maintained on a current basis by annually photographing improved, modified, and new sections of freeways.

SUMMARY

The aerial photography inventory has been used extensively and enthusiastically for a wide variety of purposes. These applications include the fields of traffic engineering, research, planning, design, maintenance, and public relations.

Such uses of the photographs have resulted in increased productivity at decreased costs.

Use of Aerial Photography in Freeway Traffic Operations Studies

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For years, traffic engineers have recognized aerial photography as a potential tool to be used in solving traffic operations problems. In studying a specific problem location, however, this tool was often passed over as being too expensive, and yielding data which required difficult and time-consuming analysis; data could be collected by more conventional traffic engineering procedures.

The recent recognition and increasing use of a systems approach, as opposed to the isolated problem approach, has caused the traffic engineer to review study procedures to find the ones most appropriate for use with this new philosophy. Problems on urban freeways have had much to do with this development. Often the traffic engineer would expend much time, energy, and money to solve a problem at a particular point where congestion was regularly observed, only to find out later that the real source of the problem was some distance away. Advanced technology in the coordination of large traffic signal networks also has prompted greater attention to system considerations.

An experimental study of obtaining time-lapse photographs from the air was undertaken in Los Angeles to determine the feasibility and application of such techniques for studying traffic operation along a considerable length of freeway. In general, the experiments proved highly successful, since it was determined that a certain type of freeway study can be made which yields important results, and which utilizes the advantageous features of aerial photography and minimizes the time in which an analysis can be made. This paper describes the procedures used in making aerial photographic density studies and presents sample photographs and sample analytical results. A new method of presenting freeway operations data, the density contour map, is described and illustrated, and the use of the map in determining origin, duration, and extent of congestion is discussed.

•ONE AREA of traffic engineering in which significant application of aerial photography has been made is the study of freeway traffic operations. Freeways, much maligned as they are, form the backbone of urban transportation systems. They serve tremendous volumes of persons and goods at speeds once possible only in intercity travel, at levels of safety many times that on surface streets, and with personal convenience and flexibility not known in other modes of mass movement. The knowledge that serious freeway operational malfunctions do exist, however, is by no means the exclusive property of the traffic engineer, as any city dweller is quick to point out. It is

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generally believed ways and means can be developed to minimize both the frequency and the detrimental effects of freeway malfunctions. Much concentrated engineering effort is currently under way with the objective of optimizing freeway traffic operation.

In dealing with the problem, the engineer must first gain a comprehensive understanding of the nature of freeway operations by collecting, analyzing, and interpreting factual traffic data. Study techniques commonly applied to other types of traffic facilities often do not meet the freeway information requirements, and their inflexible application in this changed environment can lead to faulty interpretation of the problem. This paper discusses the application of aerial photography, a well known but (in the past) not a commonly used traffic study tool, which has added to the understanding of freeway operations.

The use of aerial surveys in traffic studies was reported by Johnson (1) in 1927, well before the traffic engineering profession was formally organized. Greenshields (2) was an early proponent of photography in general, and in 1947 (3) he reported experiments in which aerial photographs were taken from a blimp and a helicopter. Several types of cameras were used successfully, and interesting discussion was set forth regarding the analysis of traffic data contained on the photographic records. In 1952, Forbes and Reiss (4) discussed the application of 35-mm time-lapse photographs for the study of driver behavior. A recent interest of Forbes has been the development of a technique for taking photographs from a low-speed light aircraft in order to study vehicle interaction within platoons. In an award winning paper (5), Wohl suggested the use of Sonne stereo continuous-strip photography for traffic studies. He indicated that both volume and speed data could be collected simultaneously over a large area during a short period of time, but pointed out the need for elimination of tedious manual reduction of photographic records.

Difficulty of film analysis, probably more than any other single factor, was responsible for the limitations in use of aerial photography by traffic engineers. One reason for the difficulty was that the type of data extracted from the films was often directed along the same lines followed in analyzing data from other sources. Traffic performance parameters such as volume, speed, and headway can be measured from the air, but alternate techniques are available to do the job more quickly and economically. Another factor was that traffic engineers in the past were often able to concentrate their studies at rather well-defined, isolated problem locations. For such study requirements, aerial photography cannot be justified. On the other hand, when field study manpower is limited, or when the objectives of study are research oriented, photographs provide a permanent record of traffic conditions on which a variety of analyses can be performed without returning to the field. Consequently, the bulk of the photographic work done in the past has been oriented toward research rather than to operations.

FREEWAY AERIAL PHOTOGRAPHY STUDY

During 1961, a freeway operations study was conducted in Los Angeles for the California Division of Highways. One phase of this work was an experimental study of obtaining time-lapse photographs from the air to determine the feasibility of such techniques for studying traffic movement along a considerable length of freeway. In general, the experiments proved highly successful, since it was determined that a certain type of freeway study can be made which yields practical results, and which utilizes the advantageous features of aerial photography without the drawback of time-consuming analysis. The traffic parameter measured was density.

Density

Several earlier studies (6, 7, 8) have indicated that traffic density, in vehicles per lane-mile, is an excellent single measurement of the level of freeway operation. Difficulty has arisen regarding this measurement, however, primarily because it has a distance base and traffic measurements are usually made at a fixed point. In early work independent ascertainment of the number of motor vehicles and their speed were made at a fixed point and density was computed:

$$\text{Density} = \frac{\text{No. of vehicles}}{\text{Speed}}$$

in which

Density = vehicles per mile;
No. of vehicles = vehicles per hour** (often called traffic volume or traffic density); and
Speed = miles per hour.

Electronic equipment is now available for measuring both traffic volume and speed with a single sensing unit and performing the computation of density on line with an analog device.

A second method for determining density is ground photography. Here, time-lapse photographs are taken from a freeway overpass and density determined by counting the number of vehicles contained within a relatively short roadway length of several hundred feet. Because of the short distance base used, individual density measurements have a high degree of variability; hence, several frames must be analyzed and data combined to stabilize the results. The use of either of these methods is restricted, for if a whole freeway is the object of study, many stations must be established and a substantial outlay of equipment and manpower is required. Comprehensive research efforts of a long-range nature, where the ultimate objective is a positive regulation of freeway traffic to optimize performance and thereby protect the capital investment, can justify expenditures of this nature.

There remains the need, however, for an economical method for measuring level of operation on a whole freeway, locating approximate sources of recurring congestion, and determining the extent of congestion in both time and distance. An aerial photographic density study is one method which meets these requirements.

Study Procedure

The general procedure used in taking aerial photographs for the purpose of measuring freeway traffic density involved flying an aircraft repeatedly through a corridor directly above the freeway section under study, and taking time-lapse photographs in such a manner that complete photographic film coverage of the freeway was obtained during each pass of the aircraft and aerial cameras over the section of freeway.

Cameras. — Three types of cameras equipped to operate in a time-lapse mode were used, providing photographs at sizes of 16 mm, 70 mm, and 5 × 5 in. Although all three cameras yielded successful results, the K-24 camera (with format size of 5 × 5 in.) was found to be preferable for this type of work, primarily because data could be extracted from the film negatives without the use of a special projector. In addition, the K-24 camera, built for and used extensively by the military for taking aerial reconnaissance survey photography in earlier days, is a commonly available and inexpensive surplus item. It is rugged, relatively dependable, and appears to have wide application in traffic movement surveys.

Aircraft. — Two types of aircraft were flown during the experimental study, a Bell Model G-2 helicopter and a Cessna 170 fixed-wing light aircraft. The fixed-wing aircraft was selected for extensive use because of its greater speed and stability in flight. It was considered more important to cover a longer segment of freeway, duplicating measurements at 5- to 10-min intervals, which can be accomplished best with a fixed-wing aircraft, than to obtain more frequent measurements over a shorter segment, which a helicopter could handle more efficiently.

Flight and Camera Operation Plans. — The approximate mathematical relationships between the variables of film size, focal length of camera lens, frame rate, ground

**This method of computing density usually employed one-minute sampling periods, with the traffic count during the minute converted to an hourly rate.

coverage, aircraft speed and altitude, as subsequently presented, are employed to formulate the desired flight and camera operation plans.

$$\text{Film scale} \cong \frac{\text{flight height (ft)}}{\text{focal length (in.)}} = \text{feet per inch} = s'$$

$$\text{Coverage} \cong \frac{\text{flight height}}{\text{focal length}} \times \text{photograph dimensions}$$

$$\cong \text{scale in feet per inch} \times \text{photograph dimensions, in inches}$$

$$\text{Frame rate (50\% overlap)} \cong \frac{\text{flight height}}{\text{focal length}} \times \frac{\text{photograph dimension in line of flight}}{\text{aircraft speed}} \times 0.50$$

$$\cong \frac{\text{coverage in line of flight}}{\text{aircraft speed}} \times 0.50$$

As an example for flying an aerial photography strip at a height of 6,000 ft above the ground and at a speed of 95 mph, using a K-24 camera equipped with a 7-in. focal length lens, the following flight plan information can be calculated. (Approximate figures are given.)

1. Film scale is 850 ft per in.
2. Ground coverage is 4,250 ft per photograph, both in line of flight and perpendicular thereto.
3. Photography rate (for 50 % overlap) = 15-sec interval between exposures.
4. Filming time (for one 125 photographs per film roll) = 31 min.
5. Number of miles of freeway included on one roll of film = 50.

With this information at hand, a fully-detailed photographic flight and aerial camera operation plan can be formulated for a specific freeway traffic survey section. An experienced operator can reload the camera with a new roll of photographic film while in flight quite easily. Consequently, with careful planning and execution, flight time need not be wasted for this purpose.

Film Negative Analysis

If these methods are to be widely accepted as practical traffic survey procedures, analysis of the aerial film negatives must be straightforward and consume as little time as possible. Bottlenecks in data flow are often more oppressive than those encountered in traffic. In this study, analysis of the film negatives was devoted to the measurement of traffic density, based on what were considered two sound reasons. First, traffic density is a significant indicator of level of traffic service (speed) and level of throughput (number of motor vehicles) on the freeway. Second, the measurements and calculations necessary in analyzing the film negatives for traffic density are very simple, and can be obtained rapidly.

Traffic density was determined by establishing freeway subsections, usually ranging from 1/4 to 1/2 mi in length, counting from the photographic film negatives the number of vehicles contained within each subsection, and then applying the equation:

$$\text{Traffic density} = \frac{\text{vehicle count (number of vehicles)}}{\text{subsection length} \times \text{number of lanes}}$$

For example, given a four-lane freeway subsection 0.44 mi long containing 85 vehicles:

$$\text{Traffic density} = \frac{85}{0.44 \times 4} = 48 \text{ vehicles per lane-mile}$$

It is convenient to use freeway overpasses as the subsection boundaries since they are quickly recognized on the film negatives. Furthermore, the exact distances between structures are available from plans already on file, which eliminates the difficult task of attempting to measure distance by use of an engineer's scale on the photographs. Both directions of the freeway are open to analysis, but they are usually treated separately.

The ease with which the analysis of film negatives can be accomplished depends in part on the level of traffic density. Under free movement conditions, analysis is simplified because fewer vehicles are in the subsections and the longer spacing between vehicles makes counting easier. With congestion, there are more vehicles to count and the shorter spacing makes counting more difficult. In any case, the film negatives can be placed on a light table and examined directly, and as personal preference dictates, either with or without the assistance of a magnifying lens.

RESULTS

Aerial photography was taken on five separate days. Three of the days were devoted to development of the techniques during which experiments were made with different aircraft, cameras, and flight plans. During the two other days, the traffic survey aerial photographs were taken, using the preferred 5- × 5-in. size format camera and light aircraft. Overall, some 10 hours of total flight time were logged and over 10,000 photographs were taken. It is not the intention here to present results in depth or to interpret the results from the operations as regards a particular freeway. Rather, sample photographs are presented to illustrate the type of data collected by their use, and a new method of presenting traffic data, the density contour map, is explained and illustrated by typical examples.

Sample Photographs

Figures 1, 2, and 3 are typical of photography obtained by use of the camera taking 5- × 5-in. size photographs. These photographs were taken with a 7-in. focal length lens from a fixed-wing aircraft flying at a flight height of 6,500 ft above the ground and at a speed of 95 mph. The three figures include prints of the full 5- × 5-in. size and enlargements of the portion of each photograph which shows the freeway subsection for which traffic density was determined. The same freeway subsection is contained in all three illustrations, and interest is centered on the upper half of freeway subsection number nine, traffic moving from right to left on the photograph.

Figure 1 shows the freeway subsection in the state of free flow (free movement of traffic). There are 44 vehicles contained in the 0.31-mi, 4-lane, subsection yielding a traffic density of 36 vehicles per lane-mile. Free moving conditions are generally characterized by traffic densities ranging from zero to 40 vehicles per lane-mile. For this range of densities, speeds range upward from 40 mph and the number of vehicles per hour range from zero to slightly below maximum.

Figure 2 shows the subsection in the state of impending congestion. There are 60 vehicles contained in the 0.31-mi, 4-lane subsection for a density of 49 vehicles per lane-mile. Traffic densities ranging between 40 and 60 vehicles per lane-mile are generally characteristic of impending congestion, with speeds ranging between 40 and 30 mph, and the number of vehicles per hour at or near maximum.

Figure 3 shows the freeway experiencing congestion. There are 94 vehicles contained in the subsection for a density of 76 vehicles per lane-mile. Traffic densities exceeding 60 vehicles per lane-mile are usually indicative of congestion during which time speeds range downward from 30 mph and the number of vehicles per hour is less than the maximum attainable at lower traffic densities.

Construction of Traffic Density Contour Maps

A means for studying traffic density level variations over both distance and time simultaneously appeared to be desirable. Because of the use of topographic contour maps to exhibit variations in ground elevation both transversely and longitudinally, it was suspected that a similar technique could be used to illustrate variations of traffic movement characteristics in two dimensions, distance and time.

The first step in constructing a traffic density contour map is to lay out a system of rectangular coordinates with distance on one axis and time on the other. The full length

... of a freeway subsection in the state of free flow.

Figure 2. Sample photographs of a freeway subsection in the state of impending congestion.

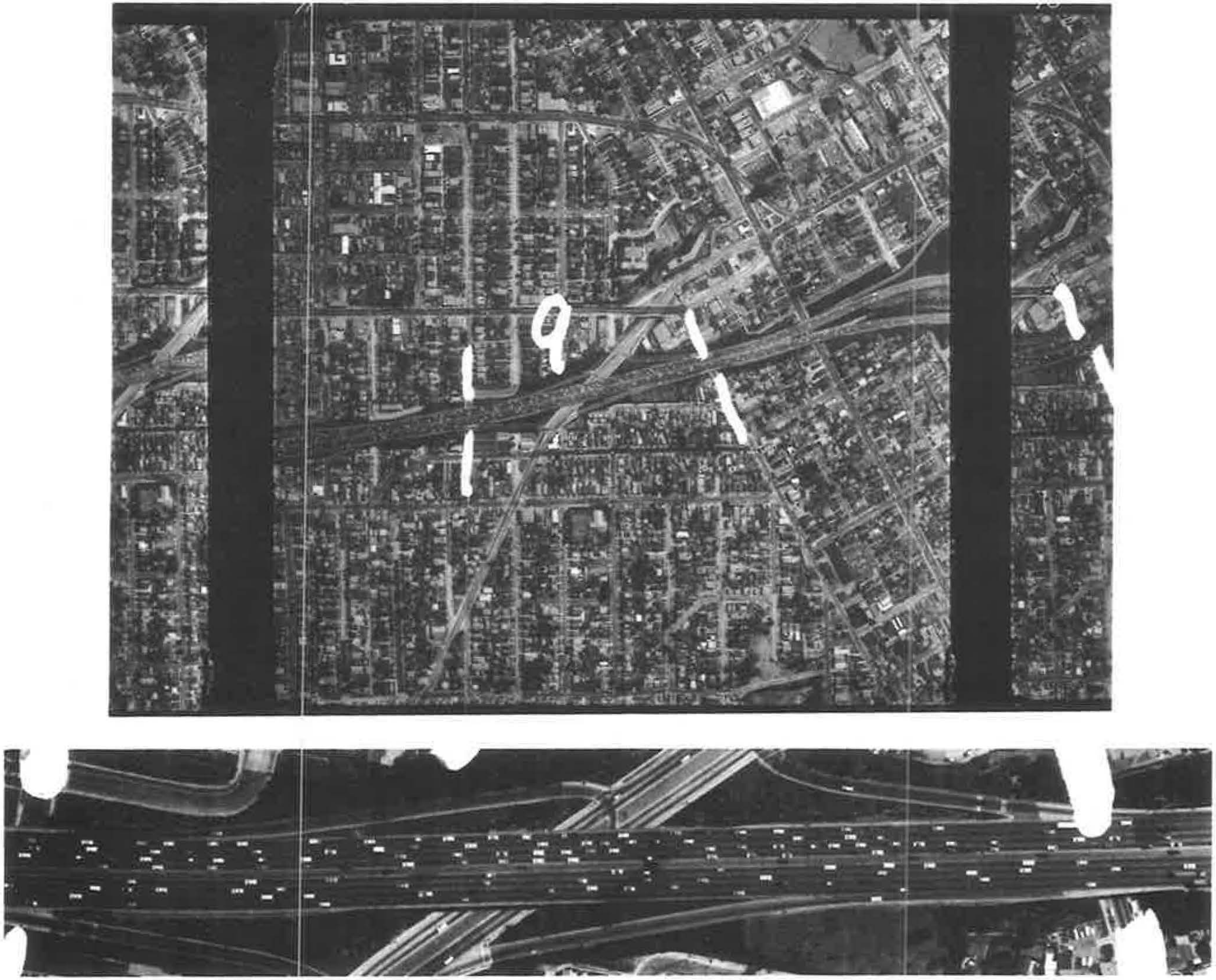

Figure 3. Sample photographs of a freeway subsection in the state of congestion.

of freeway and period of time studied may be included on the map. For the sake of standardization and to simplify interpretation of the map, it is suggested that distance and time should always be plotted in the same manner. In the examples presented, distance appears along the horizontal x-axis with direction of travel from left to right, and time is plotted along the vertical y-axis increasing upward.

The second step is to plot the traffic densities, computed for each subsection photographed during each flight over the freeway, on the graph in the proper time and distance positions. Contour lines joining points of equal traffic density are then constructed. Selection of the contour interval to use depends on the degree of detail and concentration of data and on the amount of detail desired in the completed traffic density contour map.

Sample Traffic Density Contour Maps

Sample traffic density contour maps are shown in Figures 4 and 5 to illustrate the results of this photographic analysis technique. Both maps depict traffic operation on a 7-mi freeway section during a 2½-hr period The individual traffic densities plotted on a working map and used for establishing the contour lines are deleted from the completed maps. This procedure is consistent with that used in the construction of contours on topographic maps by use of data from surveys made on the ground.

A contour interval of 20 vehicles per lane-mile is used in the examples, and certain ranges are shaded to help clarify the maps. The times and locations where smooth steady flow conditions exist (densities less than 40 vehicles per lane-mile) are shown in white. Areas of impending congestion (densities between 40 and 60 vehicles per lane-mile) are shown in light gray. Congestion (densities exceeding 60 vehicles per lane-mile) is depicted by a darker shade of gray.

Important information which can be determined by reviewing the traffic density contour maps include:

1. Approximate locations which act as sources of congestion.
2. The duration of congestion at any point along the freeway.
3. The length of freeway under congestion at any time of day .

Figure 4 is a traffic density contour map on which isolated areas of congestion are depicted. Several observations can be made:

1. One area of congestion has its source at approximately the 1¼-mi point at 4:10 PM.
2. The congestion persists for about one hour at the 1-mi point.
3. The congestion extends for a distance of approximately three-quarters of a mile beginning at the ½-mi point.
4. A second major area of congestion slightly more than one mile long begins at 4:40 PM centered at about the 4½-mi point.
5. This congestion also persists for one hour at its source, lasting until 5:40 PM.
6. Congestion extending over the 1-mi section was not backed up into the area in which earlier congestion was experienced.

Figure 5 is another example showing heavy congestion. Several observations can be made:

1. Congestion has its source near the 4¾-mi point at approximately 4:20 PM.
2. Congestion persists at this point for more than two hours, lasting until 6:30 PM.
3. Congestion extends backward to nearly the 1-mi point at 5:30 PM, and forward movement of traffic is affected to the 5½-mi point.

Other Potential Uses

In addition to the basic freeway operations information which the traffic density contour maps yield — the source, duration, and extent of congestion — other applications of the maps come to mind. For example, a single figure of merit, average

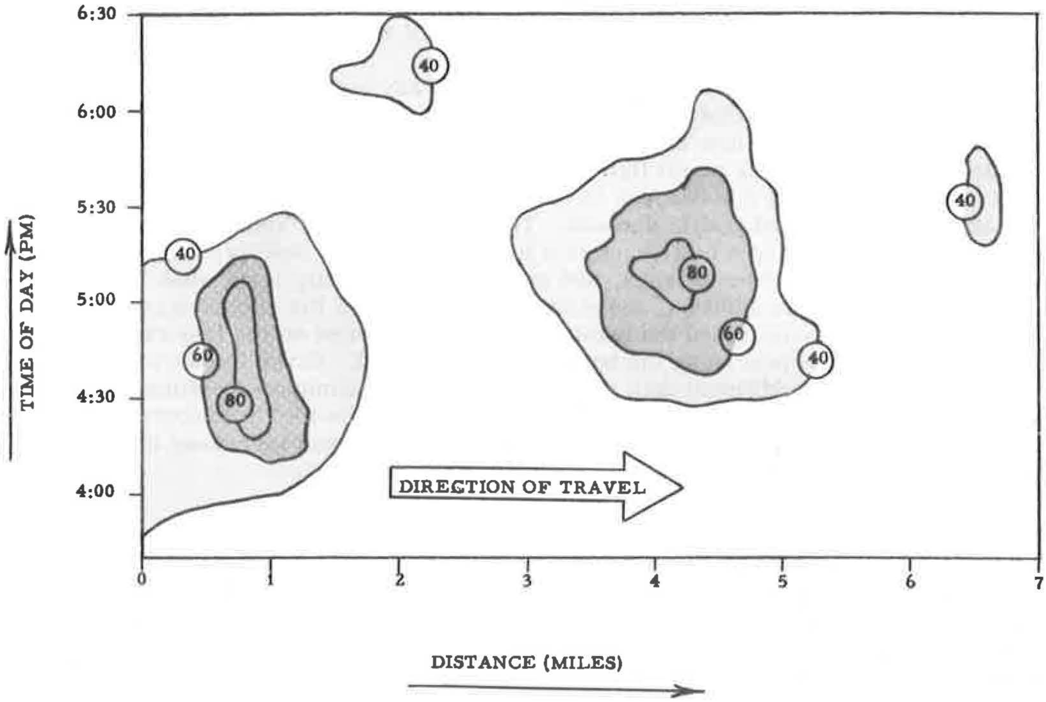

Figure 4. Freeway density contour map showing isolated areas of congestion.

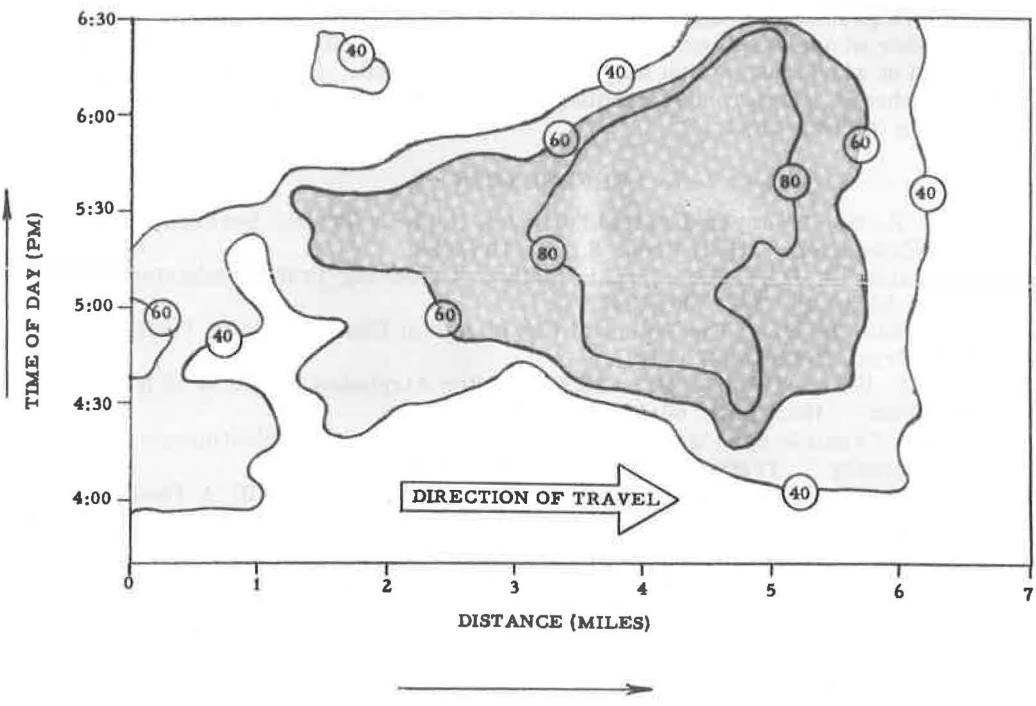

Figure 5. Freeway density contour map showing heavy congestion.

density during the time period and for the length of freeway shown could be computed by determining the areas enclosed by the contour lines, multiplying by the average density between lines, and dividing by the total area of the map. This procedure could be completed quite easily with the use of a planimeter.

Another type of analysis, the application of which has not yet been fully developed, involves the estimation of traffic demand. The number of vehicles passing through a bottleneck is indicative of how many are getting through, but this number does not indicate how many vehicles would like to pass this point (demand). The increase in traffic density preceding a bottleneck is essentially a measure of the difference between the maximum number and traffic demand. The total number of vehicles "stored" on a freeway seation preceding a bottleneck is a function of traffic density, length of the section in question, number of lanes, and selection of a density level when "storage" is assumed to begin. In addition, the storage of vehicles on the entrance ramps upstream from the bottleneck and the number of vehicles stored on the freeway desiring to leave at exit ramps preceding the bottleneck are needed. Given the aerial photography results, the only additional data needed to apply the technique of estimating traffic demand are the ramp counts. Traffic demand information is highly important for it is a basic requirement in an evaluation of the effect that proposed increases in freeway capacity will have on the level of traffic operation.

CONCLUSIONS

It is hoped that experiences in the use of aerial photography in freeway operations studies reported herein have been of interest to traffic engineers and all other users of aerial photographs and that some good has been done in the promotion of accelerated application of aerial photography for such purposes. With the rapid development of sophisticated aerial survey reconnaissance methods which have recently received broad publicity, as regards military applications, significant advances in use of aerial photography by traffic engineers seem highly probable.

ACKNOWLEDGMENTS

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REFERENCES

1. Johnson, A. N., "Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington." HRB Proc. 8:106-115 (1928).
2. Greenshields, B. D., "Photographic Method of Studying Traffic Behavior." HRB Proc. 13 (pt. I): 382-396 (1933).
3. Greenshields, B. D., "The Potential Use of Aerial Photographs in Traffic Analysis." HRB Proc. 27:291-297 (1947).
4. Forbes, T. W., and Reiss, R., "35 Millimeter Airphotos for Study of Driver Behavior." HRB Bull. 60:59-66 (1952).
5. Wohl, M., "Vehicle Speeds and Volumes Using Sonne Stereo Continuous Strip Photography." Traffic Engineering (June 1959).
6. Lighthill, M. J., and Whitham, G. B., "On Kinematic Waves II: A Theory of Traffic Flow on Long Crowded Roads." Proc. of the Royal Society, Series A, Vol. 229 (1955).
7. Edie, L. C., and Foote, R. S., "Traffic Flow in Tunnels." HRB Proc. 37:334-344 (1958).
8. May, Jr., A. D., and Wagner, Jr., F. A., "Headway Characteristics and Interrelationships of the Fundamental Characteristics of Traffic Flow." HRB Proc. 39:524-547 (1960).

Development of the Sky Count Technique for Highway Traffic Analysis

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•PERSONNEL of the Port of New York Authority who are actively engaged in aerial photography for traffic survey purposes do not consider themselves experts in the field of aerial photography. Also, they are not exclusively concerned with the study of traffic movement on highways. There are other groups in the Authority that specialize in these fields and work is coordinated with them in the application of techniques to fulfilling particular information needs.

Project Sky Count's speciality is transportation operations analysis. Other fields have been entered as a result of the search for new analytical tools. The need for comprehensive measurement of transportation activities on a regional basis has provided the principal impetus for current work.

Having entered the field of aerial photographic analysis as related to all forms of transportation, it was found that the potential for improved operational analysis was so promising that a formal systems development program was established to exploit the advantages of aerial photographic data collection.

In view of the many vehicular facilities which are operated by the Port Authority, it was natural that, as a first step, applications for photographic analysis were sought in the field of highway transportation. Although this initial phase began more than a year ago, the project is still primarily occupied with highway traffic analysis.

The goal is to develop useful techniques for analyzing areas and operations of interest to the Port Authority. Accordingly, systems have been tailored to fit the operational needs and capabilities of a particular organization. To the extent that these are universal needs and capabilities, several methods suitable for widespread application have been developed.

BASIC EQUIPMENT

To implement photographic studies of highway traffic, a 12-in. focal length camera and a single-engine airplane have been used. On aerial photography missions, the aircraft operational speeds have ranged from 80 to 100 knots and flight heights above ground from 6,000 to 10,000 ft. Recently, a 6-in. focal length lens for the aerial camera was acquired, and modification of one helicopter to carry this instrument is being considered. Data reduction has been directly from 9- by 9-in. size film negatives on a specially designed light table. Scale of most of the photographs has ranged between 600 and 900 ft per in. Because data reduction is the most time-consuming element of the system, the use of computer-linked coordinate readers for the automatic computation and processing of digital information is currently being investigated.

LINCOLN TUNNEL APPROACH STUDY

The first aerial traffic study using aerial photographs was carried out over the western approaches to the Lincoln Tunnel (Figs. 1 and 2). Initially, an experimental aerial photography flight was made 6,000 ft above the ground with the camera taking ten photographs per minute. Results of this test flight indicated traffic speed, traffic

Paper presented at January 1963 meeting of the Committee on Photogrammetry and Aerial Surveys.

Figure 1. Lincoln Tunnel approaches: (left) New Je
Underpass to West Portals (T = tunnel bound

Turnpike to Union City Underpass; (right) Union City
ic, P = portals, flight height = 10,000 ft).

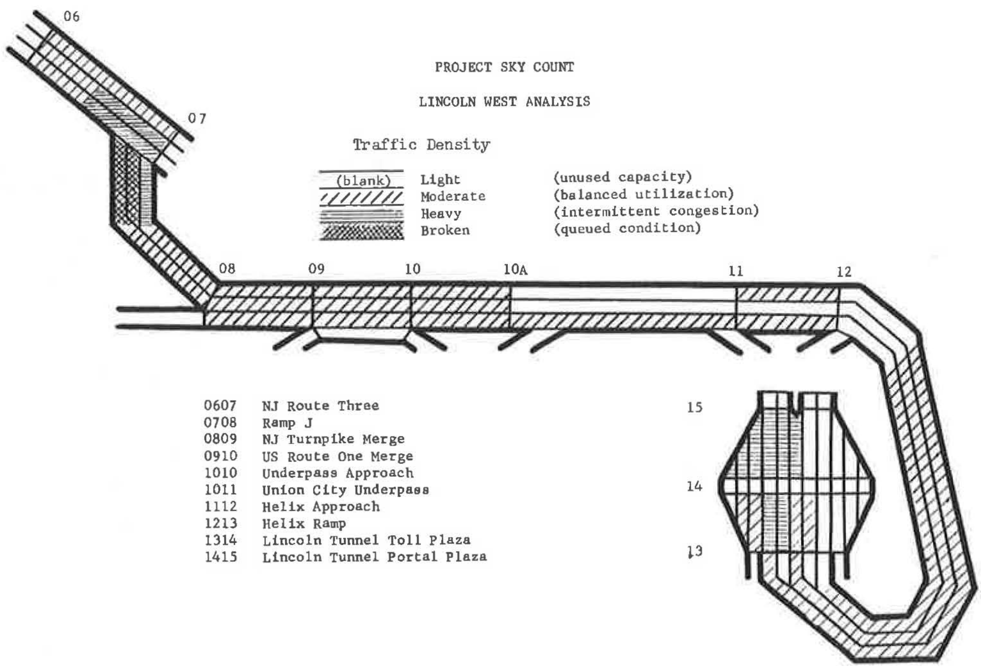

Figure 2. Average traffic conditions, 0740 to 0840, Lincoln Tunnel approaches.

density, and number of vehicles could be calculated on a sampling basis from selected sequences of 3 photographs.

Following the initial photography flight, a pilot study was carried out for a 60-min period during a morning peak traffic hour. During this photography mission the aircraft was flown 10,000 ft above the ground and the time interval between each photographic exposure was shortened to 5 sec. The study area extended from the New Jersey Turnpike to the Lincoln Tunnel west portals, a distance of approximately three miles.

Aerial photography procedure consisted of a photographic flight every seven minutes for one hour. During each photographic flight, 11 or 12 aerial photographs were taken in approximately one minute. To assure the necessary accuracy for subsequent speed determinations, a time control check was made during each photographic flight to establish correction factors for the intervalometer which controlled the camera cycle.

For analytical purposes, the traffic survey zone was divided into 10 unidirectional segments, which together constituted the principal traffic route from the turnpike to the tunnel. The 10 segments were analyzed separately in the following manner:

1. Three photographs were selected from each photographic flight to compile a series of 10-sec samples uniformly distributed throughout the study period.
2. Vehicular speeds were determined from comparison of the first and third photographs of each sequence, while the mid-photograph of each three was used for counting the number of vehicles in the segment.
3. Traffic density was determined by dividing the number of vehicles in each segment by the segment length, and traffic speed was calculated by averaging the speeds of individual vehicles.
4. Total number of vehicles per unit of time on a spot basis was calculated by multiplying vehicle speed by density, and these numbers in turn were averaged to obtain the number of vehicles per hour for each segment.

Further calculations yielded average speed and concentration of traffic for selected time periods, en route travel time through the network, and the relative productivity

TABLE 1

AVERAGE TRAFFIC STATISTICS BY CLASS OF VEHICLE AND BY LANE, UNION CITY UNDERPASS (0740-0840, SEPTEMBER 27, 1961)

LANES	DATA	AUTOS	TRUCKS	BUSES	ALL VEHICLES
Right	Population	4	17	2	23
	Density (vpm)	7.6	29.9	2.7	40.2
	Speed (mph)	14.3	13.7	17.0	14.1
	Volume (vph)	109	410	46	565
	Time (min)	2:21	2:27	1:58	2:23
Center	Population	17	2	3	22
	Density	29.9	3.1	5.4	38.4
	Speed	28.0	23.9	28.1	27.7
	Volume	838	74	152	1064
	Time	1:12	1:24	1:11	1:12
Left	Population	20	0	5	25
	Density	34.8	-	8.9	43.7
	Speed	30.5	-	29.2	30.2
	Volume	1060	-	260	1320
	Time	1:06	-	1:09	1:06
All Lanes	Population	41	19	10	70
	Density	72.3	33.0	17.0	122.3
	Speed	27.8	14.7	26.9	24.1
	Volume	2007	484	458	2949
	Time	1:12	2:17	1:15	1:23

of various route segments. For critical roadway areas, this information was compiled both by class of vehicle and by lane (Table 1).

AIRPORT EXODUS SURVEY

The second highway survey was carried out over the world's most active aviation facility, New York International Airport (Fig. 3). The purpose of this study was to measure the magnitude and intensity of all highway traffic leaving the airport during a 2-hr period.

Photographic flight planning for the airport survey was complicated by the scattered locations of four principal exit points and the interior highway routes leading to them from the central terminal and service areas. Furthermore, the flight height above

Figure 3. New York International
(right) Terminal City comp

·t: (left) Terminal City approach;
:light height = 8,000 ft).

Figure 4. George Washington Br
(right) eastern approach

(B): (left) western approaches;
light height = 10,000 ft).

the ground was reduced from 10,000 to 8,000 ft in order to maximize the size of vehicular images.

Traffic survey data accumulation from the photography, and data reduction and summarization were accomplished by following the basic methodology developed for the Lincoln Tunnel approach study, but several improvements and refinements were incorporated. Following the determination of speed, density, and number of vehicles per hour for each of the sample periods, a histogram of outbound traffic movement was prepared. From this graph it was possible to determine both the peak hour of traffic activity and the time at which the maximum number of vehicles occurred.

A coordinated field check of outbound traffic in number of vehicles per hour on Van Wyck Expressway was provided by members of the traffic engineering staff. Comparison of Sky Count and field count statistics for this route revealed a variation of one-half of 1 percent for the 2-hr study period.

GEORGE WASHINGTON BRIDGE ANALYSIS

Having established the Sky Count technique as an effective method for traffic surveys by use of large-scale aerial photographs, the project was asked to employ the system to study a small but extremely important section of 8-lane highway, the center span of the George Washington Bridge (Fig. 4).

The requested study period was three hours; from 4:00 to 7:00 PM on a Friday in July. Speed, density, and vehicles per hour statistics were required for each of the eight bridge lanes in 10-min increments (Fig. 5).

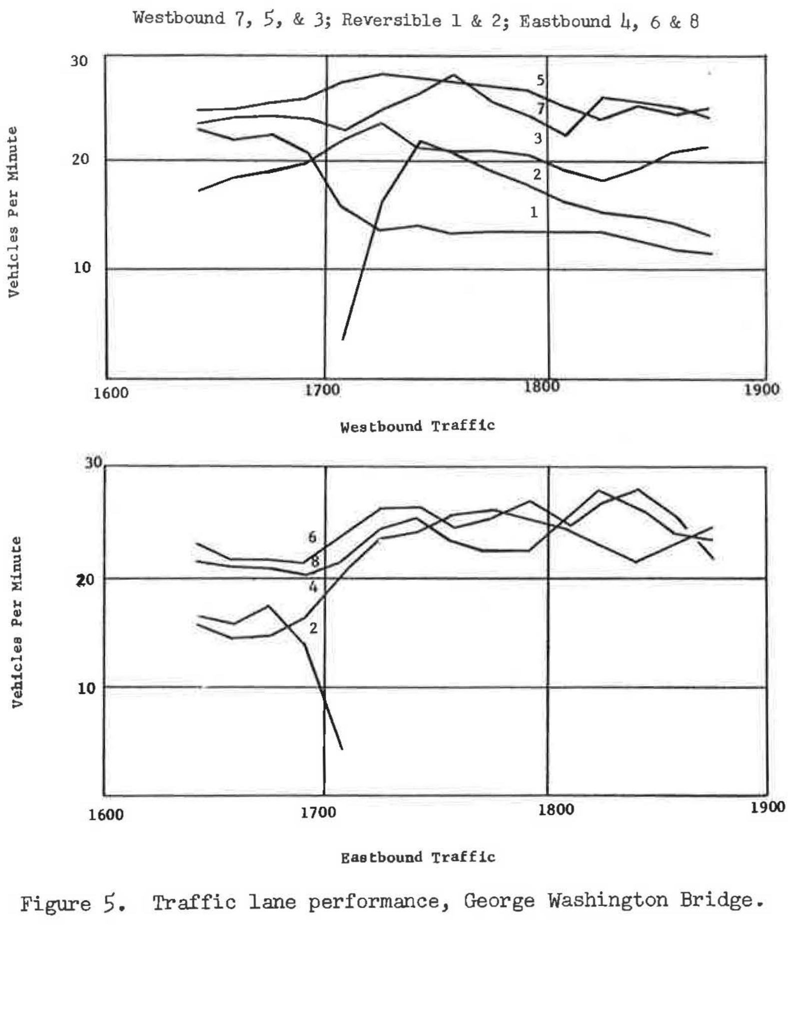

Figure 5. Traffic lane performance, George Washington Bridge.

On this aerial photography mission the aircraft was flown at a height of 6,000 ft, a lower height than had been planned but necessary because of a prevailing cloud ceiling (Fig. 4 is from a different mission). The photography flights were made at 8-min intervals with the camera operating on an optimum cycle for taking 12 photographs per minute. This aerial photography cycle has become standard for Sky Count traffic surveys to assure compatibility with standardized data reduction procedures, which have been designed to yield speed information based on a 10-sec sample of 3 photographs. A time check of the camera intervalometer was made during every third photographic flight.

As with the previous aerial surveys, correlation was obtained with independent traffic determinations of the number of vehicles per hour. A variance of less than 1 percent was found between total Sky Count of traffic in vehicles per hour and bridge toll transactions for the 3-hr study period.

POPULATION SAMPLING TECHNIQUE

The system which has been described for obtaining speed, density, and number of vehicles per hour from sequentially taken aerial photographs is necessarily complex and time consuming. Not every traffic survey requires such thorough analysis, however, and to meet the need for relatively quick and simple traffic counts, a streamlined technique for certain applications is being developed. This method is based on a raw sampling of traffic by the number of vehicles in small segments of each street or highway.

One study using this new technique has been conducted: a reversing lane analysis at New York International Airport. The purpose of this survey was to provide peak hour traffic counts for 23 reversing lanes located in the median areas of the airport highway system.

Because sequentially obtained photographic coverage of the airport was available from a previous Sky Count study, it was not necessary to conduct original photographic flight operations for this traffic survey. Using the film negatives on hand, the number of vehicles utilizing various reversing lanes was determined as a function of the sample duration. After summarizing the counts and durations of all samples, hourly estimates for each segment were established by projection.

The average size of traffic survey sample obtained was 7 percent of all traffic, but some samples ran as high as 9 percent. If specialized photographic flight procedures are employed, it appears that sample sizes of up to 20 percent may be obtained. In view of the simplicity and effectiveness of this technique, it is planned to develop the concept further as a supplement to the regular system.

HIGHWAY RESEARCH APPLICATIONS

Another area of interest to the Port Authority is highway traffic research. In cooperation with members of the research staff, the use of sequentially taken aerial photography as a measurement tool for the study of basic traffic phenomena is being investigated.

The first use of the system in this connection was made by Dr. Renfrey Potts of the University of Adelaide, Australia. Dr. Potts asked for permission to use some of the film negatives of the sequentially taken aerial photography for a study of platoon acceleration. The film negatives of the airport exodus survey were provided with the understanding that he would reciprocate by making the results of his research available. Dr. Potts has recently completed a preliminary study of platoon acceleration along a section of a 4-lane highway. In this study the trajectories and interactions of more than 40 vehicles have been analyzed in considerable detail.

REGIONAL TRAFFIC ANALYSIS

Perhaps the most interesting and potentially significant work that has been carried out by Project Sky Count lies in the field of regional transportation analysis.

In addition to conducting a land economics survey of the Hudson River Valley, the project has participated in a study to determine potential traffic diversion from the Tappan Zee Bridge to the George Washington Bridge. A diversionary influence is presently being created by the completion of the George Washington Bridge lower level, the Alexander Hamilton Bridge, and the Cross-Bronx Expressway.

To analyze quantitatively this influence, it was necessary to examine the present utilization of all routes serving the two bridges on both sides of the Hudson River. The study zone extended from Throgs Neck to Rye on the east and from Paterson to Suffern on the west, an area of more than 600 sq mi.

After considering a number of methods for measuring traffic movements throughout this large area, it was decided to dispense with the aerial camera in favor of visual data collection. The principal factor influencing this decision was speed. By flying a carefully planned route, it was possible to pass within visual range of each segment in the study area at 40-min intervals.

A visual judgment of traffic activity was made while passing over each segment. The evaluation was based on a traffic rating scale of 5 increments ranging from virtually no traffic to solid congestion. In this manner it was possible to rate more than 100 highway route segments throughout the area of study every 40 min.

During a 4-hr survey, six ratings were obtained for each segment. Average traffic conditions were computed from the individual ratings and these were used to calculate speed, density, and vehicles per hour based on average performance curves developed from previous photographic traffic surveys. Three of these visual rating surveys were conducted during periods of peak traffic. Flight height above the ground was limited to 3,000 ft by local visibility conditions.

The principal advantage of this method relative to aerial photographic techniques is the wide and rapid coverage which it provides. Another important advantage lies in the adaptability of this technique to night operations.

CONCLUSION

The work undertaken to date has touched on many important aspects of highway planning, design, and research. It is felt that aerial traffic analysis, however, has yet to be exploited enough to ascertain all of its potentialities. An extensive study of traffic interaction in midtown Manhattan and studies of traffic signal effectiveness and shock wave transmission are planned.

Few fields of study can derive as much benefit from the application of aerial photographic techniques as the field of highway traffic analysis. A large variety of effective study techniques may be developed using sequentially taken aerial photography as the basic data collection medium. Potential uses for these techniques are virtually unlimited.

ACKNOWLEDGMENTS

The project group consisted of John R. Shelton, Justin H. Dickins, Thomas D. Jordan, and Frank N. Caggiano. This project has been implemented under the direction of Mr. Shelton of the Operations Standards Division, who has provided the all-important mental and physical environment for effective development work.

Adoption of Aerial Survey Methods for Traffic Operations

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• EFFICIENT OPERATION of a modern highway transportation system requires continuing attention to the current and foreseeable traffic trouble spots, the necessity for development and use of new traffic control methods, and continuing research on traffic characteristics to assure the safest possible operation. To accomplish these functions the traffic operations engineer must use his resources in the most profitable way possible. This usually means spreading himself very thin, since problems affecting most highway users occur between the hours of 6:30 to 9:30 AM and 4 to 7 PM. These two

Figure 1.

Figure 2.

Figure 3.

Figure 4. Dense outbound traffic on Key Bridge further congested by a traffic accident.

Figure 5.

Paper sponsored by Committee on Photogrammetry and Aerial Surveys.

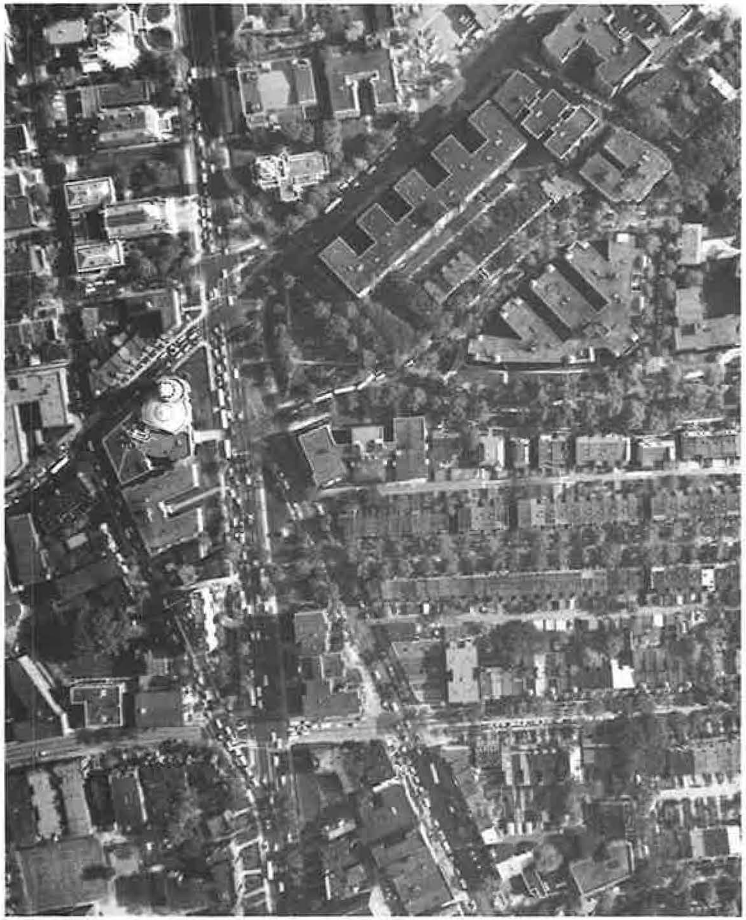

Figure 6.

Figure 7.

Figure 8.

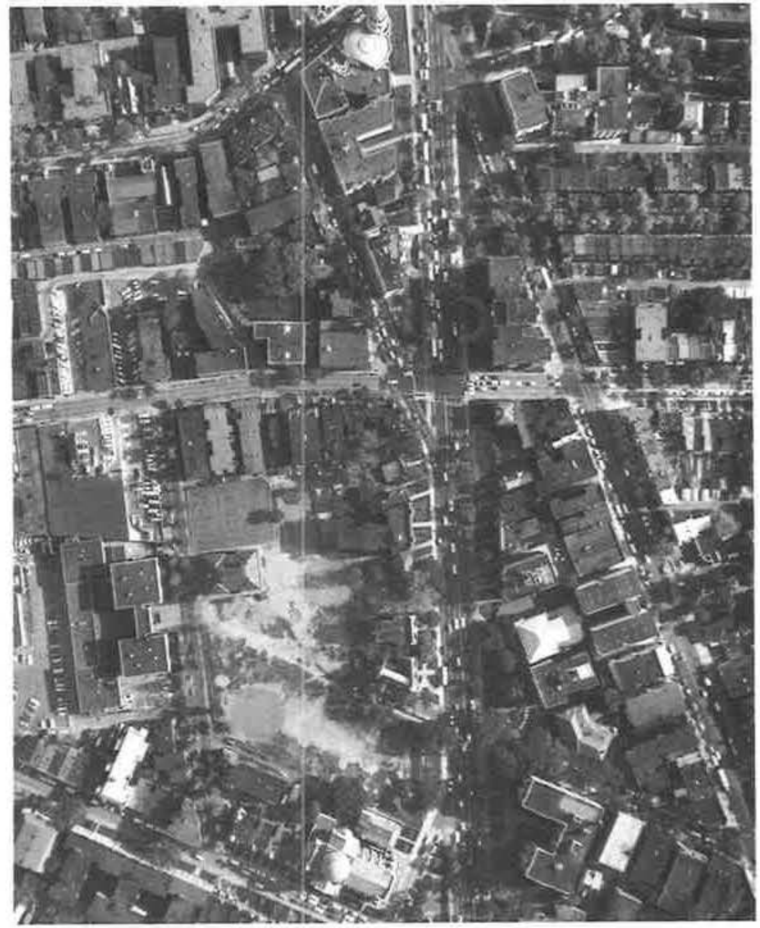

Figure 9.

periods, when traffic movement problems are the most acute, usually occur before and after what are considered normal working hours. This is significant in that methods of getting traffic data from widely-dispersed areas in short periods of time become increasingly important.

Aerial survey techniques offer an unusual opportunity to meet these demands in scope and detail during the critical traffic hours. Airborne photographers can be dispatched to problem locations and capture an event on film for study or reference. Further, since most traffic events have both cause and effect relationships, the extent of the effect can often be recorded and used as a check on office analysis of a problem.

A recurring demand of vehicle operators for more efficient service from the highway systems (that their gasoline taxes pay for) is the improvement of safety and the reduction of bottlenecks on commuter routes. Several cities have airborne traffic surveillance on a continuing, scheduled basis. Various means of identifying traffic-movement trouble spots have been attempted in the Washington Metropolitan Area. The examples used in this paper combine experience obtained through cooperation with the Metropolitan Police Department of the District of Columbia and through the courtesy of the U. S. Army in making available training flight time.

In 1960, aerial observation of several bottleneck points during periods of peak traffic was used by helicopter-borne traffic engineers on several successive days. In late 1961, personnel of the Traffic Division of the Metropolitan Police Department, in cooperation with a local radio station, began broadcasting traffic information from a small helicopter during peak traffic periods. In November 1962, a larger aircraft was obtained and an invitation was extended to engineers of the Department of Highways and Traffic to use the third seat for traffic operations work. This offer was accepted to obtain information on the efficiency of arterial highway systems and operation of detours. The advantage of such joint usage of aircraft is that the recurring problem areas, well known to police personnel, can be subjected to joint enforcement and engineering inspection, and in some instances a course of action may be decided while viewing the problem.

All aerial photographs were taken from a helicopter at flight heights ranging from 200 to 2,000 ft. The operational photographs were obtained using photographic film of A. S. A. speed rating 200 in either a Kodak Signet or an Argus C-3 camera held in the engineer's hand. The time lapse photography was obtained with a K-24 aerial camera equipped with a 7-in. focal length lens, mounted on a Bell G-2 helicopter. "Elevated" photographs were taken from flight heights ranging between about 30 ft and 110 ft above ground level.

The operational uses and advantages of aerial survey techniques fall into two general categories:

The problem category is illustrated in Figures 1 through 3. Complaints received indicated traffic congestion so severe that cars could not exit from off-street parking lots. Spot study of the problem seemed to confirm this. Upon receipt of the "elevated" photographs, however, it was evident the location of bus loading operations was the major factor. A call to the transit company and shifting of bus loading areas resulted in substantial improvement.

Another illustration of the problem category is shown in Figure 4. While airborne on routine evening rush-hour surveillance, notice was received of an accident on a bridge which was operating very close to practical capacity. Any interruption of traffic on this structure during rush hours produces a wave of congestion extending down a freeway and a major arterial street within one cycle of a traffic-control signal. Within two minutes an engineer was over the scene and obtained photographic evidence of the influence exerted, furnishing visual support that operating conditions are so critical as to create very adverse traffic conditions when subjected to the slightest inferference.

Figure 5 shows a third problem area. Here a complex intersection tends to become a bottleneck under rush-hour operation. The only way to obtain a perspective of the problem is to view it from the air. Study of the problem must also be based on data showing the overall problem.

In the research category, both precise survey type photography and non-survey photography are used. Figures 6, 7, 8, and 9 show two intersection complexes on a major

Figure 10. Intense morning traffic in two of four inbound lanes, Memorial Bridge.

Figure 11. More uniform distribution of morning traffic in the four inbound lanes, Memorial Bridge.

arterial street. These photographs were taken at 5-sec intervals for operational research on signal control systems. They are to be used for operational research on traffic movement, particularly bus lanes (when available) and for research into pedestrian crossing problems. In many instances, aerial survey photography already on file can be extremely valuable to the traffic operations engineer if made available to him. This "bonus" value is often overlooked.

Figures 10 and 11 show a non-survey research problem in lane distribution. The fourth lane from the left reverses direction during the evening rush hours, but the problem is to obtain full and continuous use of this lane as shown in Figure 11.

This brief report of operational uses of aerial, including elevated photographs illustrates how this technique can be used by the traffic operations engineer.

In summary, the problem can be viewed in its entirety, without the engineer being a part of the problem, either at the source or in the resulting congestion. Aerial photography is the effective means of getting to the trouble spot rapidly while the condition exists. It also provides a powerful tool for operational research and study of problems not otherwise approachable. There is no necessity for high-priced equipment, or even aircraft, in many instances. The bonus value of on-the-shelf survey photography provides in many instances a convenient library of photographs available on request. Potential future uses for both categories of photography include detour review and operation, and analysis of traffic movement and traffic intensity.

Finally, the traffic operations engineer should be aware that aerial photographs will not solve his traffic problems, but their use will identify new problems he did not realize existed. Consequently, although aerial photographs are an invaluable aid in making traffic surveys, and in identifying and analyzing traffic problems, engineers should remember there is no substitute for getting all pertinent facts, clear thinking, and complete analysis before the problems can be solved. With the preceding qualifications the engineer will find aerial survey methods are very valuable aids to use in his attack on traffic problems.

Use of the Kelsh Plotter in Geo-Engineering and Allied Investigations in Kansas

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Geologist I and Engineer of Photogrammetry, State Highway Commission of Kansas, Topeka

• THE USEFULNESS of aerial photography for highway engineering can be fully recognized when all possible qualitative information and quantitative data are extracted for the completion of the design and construction of a proposed highway project. Repeated observations and study of the photography by qualified personnel is necessary to accomplish this end. Information obtained from the photography in meeting these objectives culminates in the form of survey notes, geological reports, materials inventories and surveys, and in other engineering reports of various types.

In a given area, different engineering organizations would require essentially the same type and amount of field information to design and construct a project. Consequently, many of the engineering field procedures are relatively standard throughout the United States and the world. There are areas, however, where differences in investigation policies are employed with a great deal of success.

In years past, the practice of obtaining detailed geological information to be used in the design, construction, and maintenance of highways has been adopted as a routine operation in Kansas. Since the establishment of the State Highway Commission's Photogrammetry Section in 1958, this operation has advanced into the photogeology field which in turn has branched out into many of the related fields of photographic interpretation. In essence, the newer fields of photogrammetry and photographic interpretation have been recognized by the Kansas Highway Commission as an essential method of investigation.

It is the purpose of this paper to present some of the procedures and techniques used in Kansas in an attempt to obtain full employment of available aerial photography and the conditions that exist to which these procedures have been adapted. The process of acquiring a variety of field data for any particular project often involves the use of the same photogrammetric techniques. It is difficult to separate the close interrelationship of the types of information. This paper has attempted to separate the general areas with the understanding that in practice they are frequently combined into one operation.

KANSAS GEOLOGY

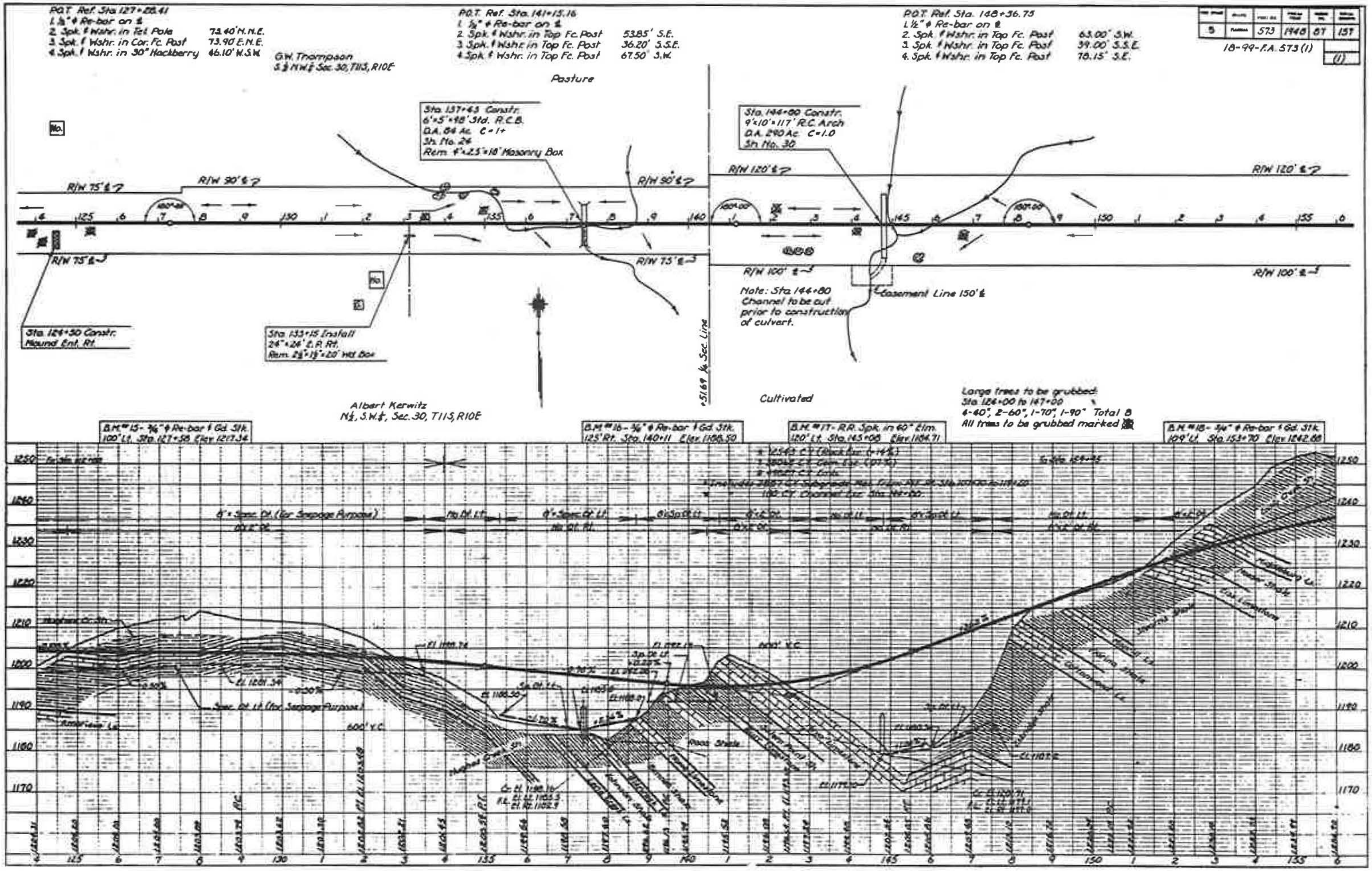
In general, the rock formations of Kansas can be described as of sedimentary origin with a nominal amount of structure dip to the west. A generalized composite section of outcropping geological formations in Kansas would range from Mississippian cherty limestone exposed in the extreme southeast corner of the State to recent alluvial deposits found along most of the major stream valleys.

The eastern one-third of the State is made up predominantly of Pennsylvanian and Permian interbedded limestone and shale. The northeastern corner of this area is overlain by Pleistocene glacial deposits.

Progressively younger beds are encountered to the west. Cretaceous shales, sandstones, and limestones dominate the terrain of the central portion of the state. In the south portion of this area, these formations are overlain by silt and sand of Quaternary age.

The western one-third of the State is characterized by continental deposits of sand, gravel, and silt of Tertiary age capped in many areas by Pleistocene silt.

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.



Pasture
Cultivated
G.W. Thompson
Albert Kerwitz
Note: Sta. 144+80 Channel to be cut prior to construction of culvert.
Large trees to be grubbed: Sta. 124+00 to 147+00

Figure 1.

Inasmuch as the Mississippian System is represented in Kansas by only a very small area, very little photographic interpretation work has been accomplished in sediments of this age. There, a further description of these beds has been omitted.

The geological formations of Pennsylvanian age are characterized by predominantly thick interbedded limestone and shales. These beds tend to thin to the west. Most of the shales thicken southward toward the Oklahoma border and many of the limestones either wedge out or grade into shale or sandstone in this direction. Reef development has also caused local thickness variation in many of these formations. Photogrammetric and photographic interpretation techniques have been used quite successfully in rock formations of this age; however, accurate and sometimes abundant ground information is necessary to cope with the local variations that may be encountered.

The Permian formations, which with the Pennsylvanian formations comprise the eastern one-third of the State, include evenly stratified predominantly marine deposits in the lower part of the section and irregularly bedded, mainly nonmarine deposits in the upper part. In the lower portion of the section, limestone beds, many of which are distinguished by abundance of flinty chert, form persistent benches or escarpments, among which the Kansas Flint Hills are most prominent. These escarpments are readily adaptable to photogrammetric and photographic interpretation techniques. The nonmarine deposits in the upper portion of the section are too erratic and inconsistent to be mapped by these procedures. Much information, however, can be obtained concerning ground-water conditions, material deposits, etc., by photographic interpretation.

Rocks of Cretaceous age are predominantly of marine origin in the upper portion of the section and of continental origin in the lower. Soft, thin limestone of late Cretaceous age is easily discernible on aerial photographs and have been mapped by using photogrammetric techniques. Sediments of continental origin (early Cretaceous age) cannot be mapped by photogrammetric methods but much information concerning the type and extent of the deposit can be ascertained from stereoscopic examination of aerial photography.

The remainder of the surface geology of Kansas is composed of Tertiary Continental stream deposits located in the western one-third of the State. These deposits are overlain in many areas by a wide assortment of fluvial and eolian deposits of varying thickness of Quaternary age. These beds cannot be mapped on the Kelsh plotter because of their great thickness, absence of an "index" bed, and their inconsistent nature. Photographic interpretation techniques have been utilized in the detection of construction material deposits and ascertaining the aerial extent of these sediments.

USE OF GEOLOGICAL INFORMATION IN DESIGN OF KANSAS HIGHWAYS

In Kansas the geological conditions rarely dictate the location of a new alignment. These conditions must be known, however, so that the designer can formulate a successful design.

It is the job of the highway geologist to provide the designer with this information. By use of a variety of augers, core drills, and penetrometers, the highway geologist obtains all pertinent geological information and presents it in report form. The characteristics of each geological formation that will be encountered is presented in terms of stability, excavation classification, and ground-water conditions.

The geology is plotted on the centerline profile and cross-sections of the proposed project. Figures 1 and 2 show a standard highway plan and profile sheet and a corresponding set of cross-sections. The designer then has a picture of the natural conditions on which he is to design a road or structure.

One of the most important pieces of information obtained through geological survey is the quantity of rock excavation that will be encountered on a given project. This information is not only of value to the designer but to the contractors who will be bidding on the project. Not only will the contractor know the quantity of rock that will be encountered, but he will have some idea of how it can be worked. This helps the contractor to determine a more accurate and consequently lower bid. Swell and shrink factors for each formation will enable the designer to adjust the grade line for greater economy in excavation. This information is also required in determining the balances

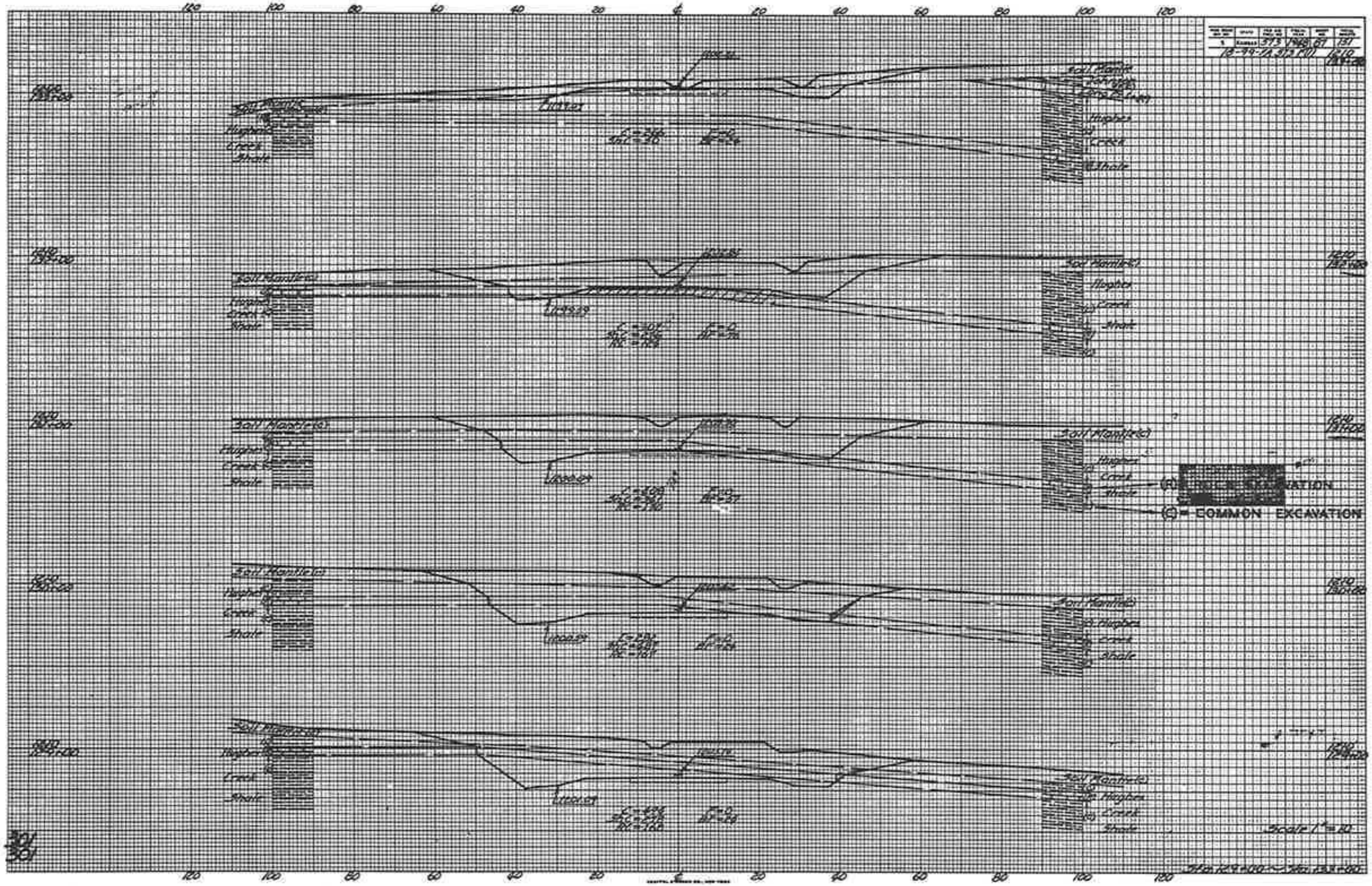


Figure 2.

between cut and fill or the necessity for borrow pits or waste areas. Where bedrock is encountered, additional excavation of the undesirable material (subgrade) will be recommended and the need for additional selected material for backfill will be specified.

If ground-water problems are encountered during the geological survey, the geologist recommends and designs underdrains to cope with the problem. The underdrain design includes the name and elevation of the aquifer, gradient of the drain, and the location and elevation of the outlet.

The stability of geological formations encountered in cut areas is presented in form of backslope gradient recommendations.

Bridge foundations studies are performed by subsurface geologists to provide information concerning depth and type of bedrock, and to recommend type and length of piles and/or types of footings. This information is used by the bridge designer to help select the most feasible bridge site, to formulate the design of the bridge, and to help estimate the cost of the structure.

Detection, prevention, and maintenance of slide areas; special ditch recommendations; channel change recommendations; and determination of sources of good construction materials are other problems that may also be worked by the highway geologist.

ADAPTABILITY OF KANSAS GEOLOGY TO KELSH PLOTTER TECHNIQUES

Because of the flat lying and consistent nature of the different geological formations, the geology of Kansas lends itself to geological field investigations. For the same reasons it lends itself to photographic interpretation and measurement and, therefore, is the key to many methods and techniques currently utilized in photo-geology investigations as used in the Kansas Highway Commission.

Both the geological field investigations and the photo-geological investigations rely on relatively consistent and discernible geology. Both methods acquire the same type of information. The field investigations are more detailed and more exhaustive in nature.

Another similarity of the two methods is the need for a geological bed or beds to correlate the geology in one area to another. The difference in the correlation procedures that the field and photo-geologist uses lies in the choice of different identifying characteristics of the correlation bed. Whereas the field geologist might use fossils, joint spacing, fresh bed color, weathered bed color, calcium content, thickness, and the relative position of the bed, the photo-geologist might use relative tone as depicted on the aerial photograph, relative position, topographic expression, joint patterns, vegetative cover, drainage pattern, and other markings that he might find peculiar to that bed.

Besides being consistent and relatively flat-lying, one of the main characteristics of Kansas geological formations which is conducive to photogrammetric measurements is that an abundance of "index" beds are available. An index bed could very well be called a correlation or reference bed that is prominent, fairly consistent, and discernible on aerial photographs. In areas adapted for this work, index beds can be located in each local area. There are some index beds that extend over a large part of the State and are subsequently described. Figures 3 and 4 show the Ft. Riley rimrock index bed in Cowley County and Geary County which are 120 miles apart.

In each area that is worked the index bed is a reference point within the geological section that is being mapped. The photo-geologist must either measure the section that will be encountered on the project in the field or obtain reliable measurements from old projects that have been worked in close proximity of the proposed project.

By having these thicknesses, the elevations of the geological formations not discernible on the aerial photograph can be accurately obtained. Subsequent to this operation, the geology can be plotted on centerline profiles and cross-sections. A figure in the Wyandotte County K-5 Report enclosed herein (Fig. 15) shows a cross-section of an area in Wyandotte County where the geology was mapped on the Kelsh plotter. If the project is over several miles long, or if the geology is inconsistent, the section may have to be measured several times along the proposed route so as to detect any lithology or thickness change in the formations.

Figure 3. Ft.Riley limestone "rimrock" index bed in Cowley County, Kans. (scale: 1:13,500).

The Kelsh plotter can be used for mapping purposes in formations in the Pennsylvanian, Permian, and Cretaceous systems. Usually several prominent index beds are located within each system.

A great deal of literature pertaining to Kansas geology has been published by the State Geological Survey of Kansas. This information combined with the data accumu-

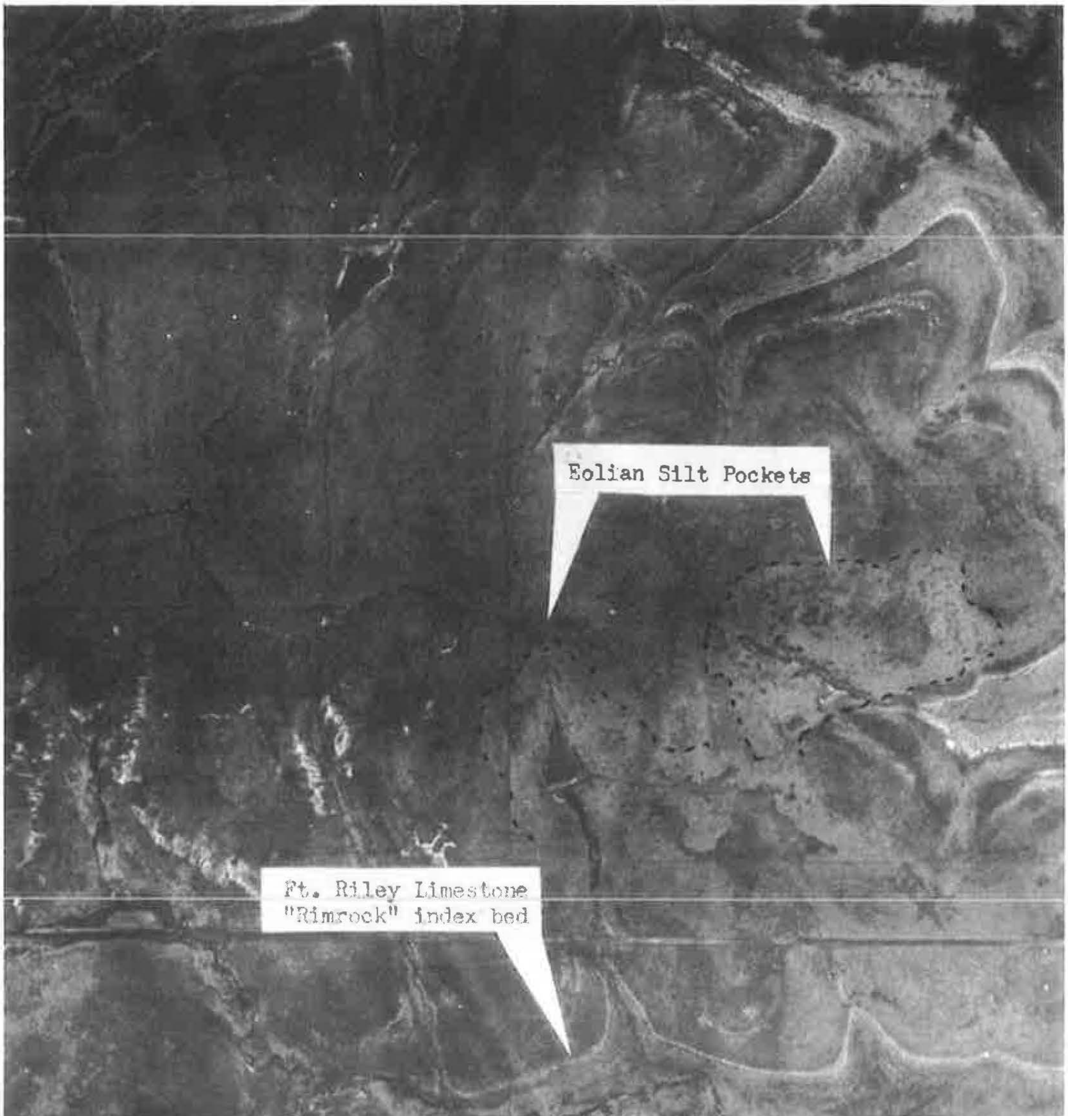


Figure 4. Ft. Riley limestone "rimrock" index bed in Geary County, Kans.; eolian silt pockets detected by gully characteristic s and tone variation (scale: 1:12,000).

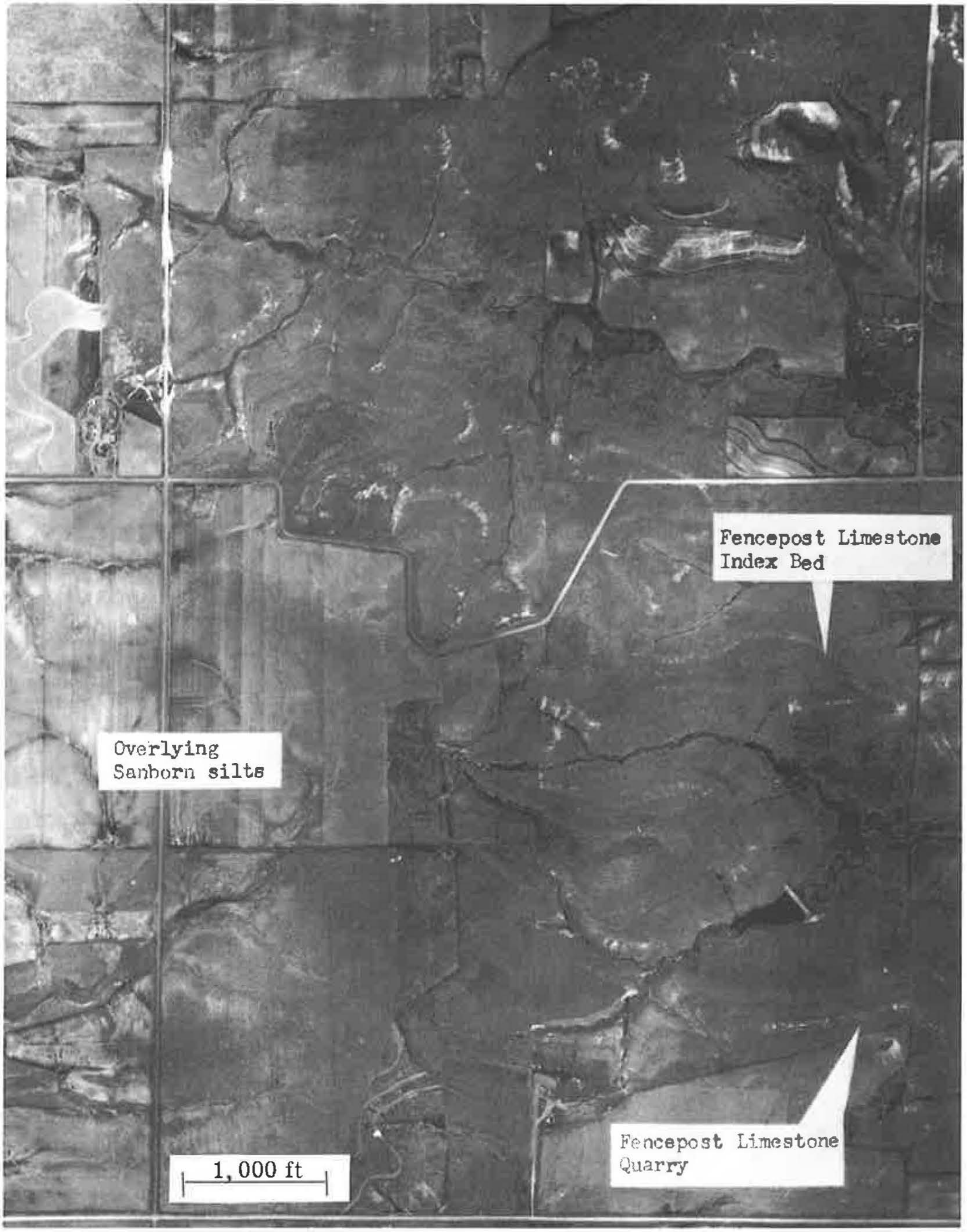


Figure 5. Fencepost limestone index bed in Lincoln County, Kans.; white band below fencepost limestone caused by band of thin chalky limestone; overlying Sanborn silts are being farmed in this area (scale: 1:12,000).

lated in the Geology Section of the Kansas Highway Commission has provided the photographic interpreter with a rich library of general and detailed information about Kansas geology. As in any other photographic interpretation activity, this "ground" information has been a tremendous aid in developing and implementing the mapping procedures currently being used.

INDEX BEDS AND TARGETS FOR GEOLOGY

An index bed can be described as a reference or correlating bed with consistent characteristics in color, thickness, and topographic expression which make it readily identifiable on aerial photography. In mapping procedures, these beds are used as a

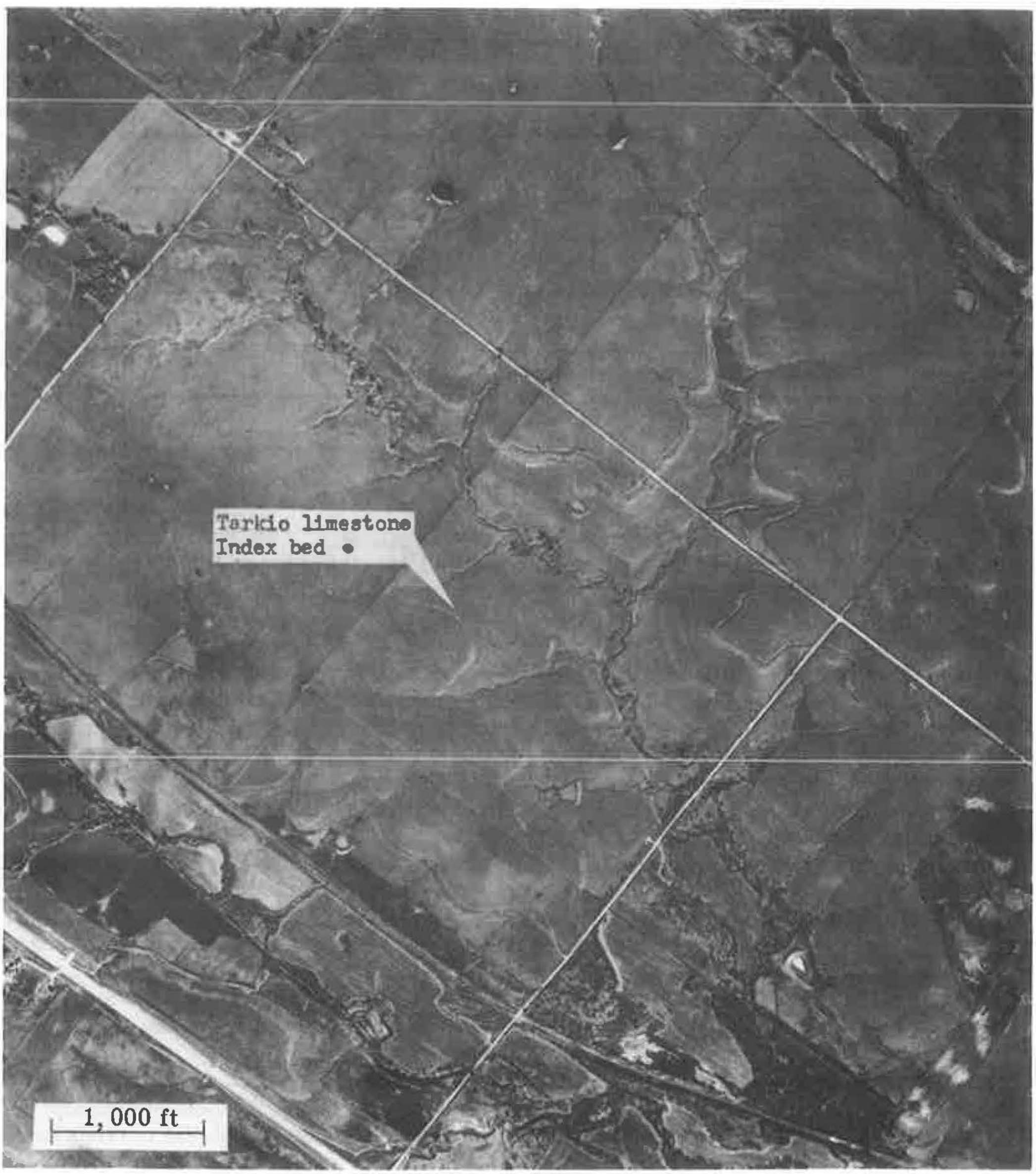
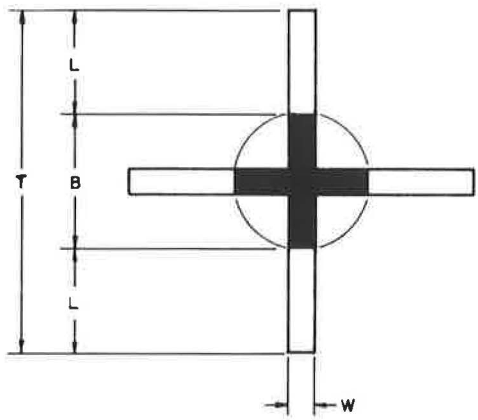


Figure 6. Tarkio limestone index bed in Jackson County, Kans. (scale: 1:12,000).



HORIZONTAL CONTROL TARGET

MINIMUM DIMENSION				
FLIGHT HEIGHT	DIMENSION T IN FEET	DIMENSION L IN FEET	DIMENSION B IN FEET	DIMENSION W IN INCHES
900	4.00	1.50	1.00	3.00
1200	5.00	2.00	1.00	4.00
1500	6.00	2.25	1.50	5.00
1800	7.00	2.50	2.00	6.00

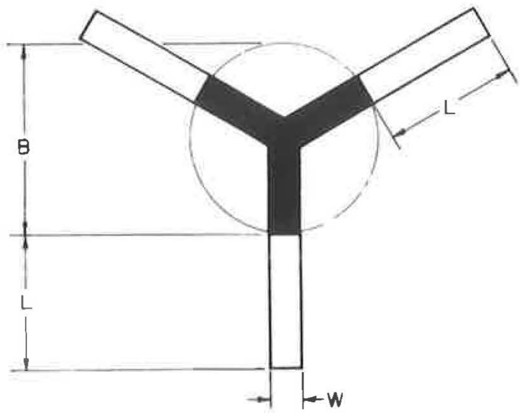
Figure 7.

"datum" from which the elevations of underlying and overlying formations are obtained by measurements on the Kelsh plotter. Some of the more prominent index beds in Kansas are subsequently described.

The fencepost limestone bed is a key index bed that is used in central Kansas. The limestone is located on top of the Pfeifer shale member, Greenhorn limestone, Colorado group, Gulfian series, Cretaceous system. Even though the thickness of this bed is approximately 0.5 to 0.8 ft, there are several features of this rock and the surrounding bedrock which identify this bed on aerial photography. Usually this bed helps to form escarpments on ledges that are typical of Greenhorn topography. A distinct vegetation change occurs at the geological contact of the fencepost limestone and surrounding bedrock which gives a banding appearance. This limestone has been quarried extensively throughout this area and the old quarry scars distinctively mark this ledge or rock. Figure 5 shows the fencepost limestone in Lincoln County, Kans.

The Ft. Riley rimrock is a very extensive bed geographically in eastern Kansas. The rimrock occurs in the lower portion of the Ft. Riley limestone member, Barneston limestone, Chase group, Wolfcampian series, Permian system. The main factor that identifies this bed on aerial photographs is its massive characteristics which make it stand out from the overlying and underlying thin bedded and relatively soft limestone. Figure 4 shows the rimrock in Geary County, Kans.

The Tarkio limestone is a prominent limestone in the upper portion of the Pennsylvanian system. This limestone belongs to the Nemaha subgroup, Wabaunsee group, Virgilian series, Pennsylvanian system. It is used as an index bed in the northeastern part of the State. This bed is relatively thick in this area and has thick overlying and underlying shales. This sequence of formations gives rise to a prominent topographic



VERTICAL CONTROL TARGET

MINIMUM DIMENSIONS			
FLIGHT HEIGHT	DIMENSION W IN INCHES	DIMENSION L IN FEET	DIMENSION B IN FEET
900	3.00	1.50	1.00
1200	4.00	2.00	1.00
1500	5.00	2.25	1.50
1800	6.00	2.50	2.00

Figure 8.

expression which can be easily discerned on aerial photography. Figure 6 shows the limestone in Jackson County, Kans.

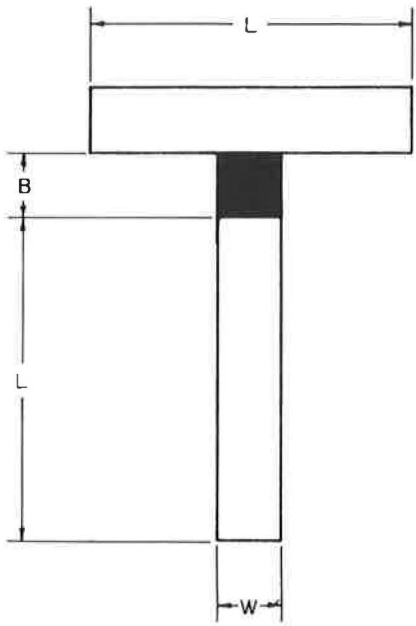
The most favorable index beds are the limestones that are underlain and overlain by thick shale formation. This is true of the three examples previously mentioned with the exception of the Ft. Riley rimrock which is located within a softer limestone formation.

Other geological formations, which are equally consistent in character and easily located on the ground but are difficult to identify on aerial photography, also cover certain large areas of the State.

During the field work which precedes the flying of photography, targets are placed to identify points of reference for the measurement of distance and elevations. If there are no index beds when these targets are laid, the geologist can also mark key geological formation to obtain adequate geological control.

Figure 7 shows the type of target used for horizontal or distance control. In Figure 8, the vertical or elevation control target is shown. The type of target used specifically for the control of geology will generally have a different shape from the horizontal or vertical control target to make them more easily identifiable. The usual shapes used in Kansas are the T, the L, the V, and the ↓. Figures 9, 10, 11, and 12 give the general dimensions of these targets.

The T-target is usually placed so that the cross-bar lies along the strike of the bed. The L-target is used in a similar manner with the shorter leg of the L running parallel



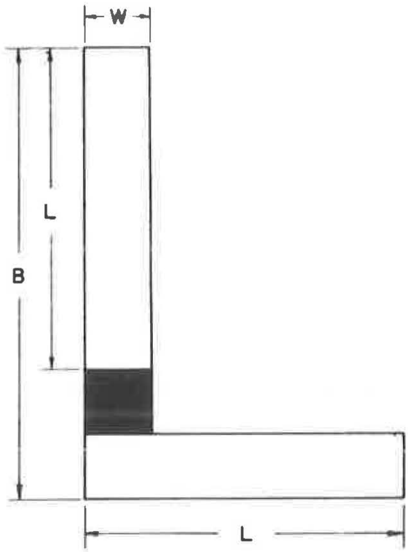
GEOLOGY T TARGET

MINIMUM DIMENSIONS			
FLIGHT HEIGHT	DIMENSION W IN INCHES	DIMENSION L IN FEET	DIMENSION B IN FEET
900	3.00	1.50	1.00
1200	4.00	2.00	1.00
1500	5.00	2.25	1.00
1800	6.00	2.50	1.00

Figure 9.

to the strike of the bed. The V- and the arrow ↓-target are placed so that the apex of the target is on the geological contact. Because the control beds being flagged are limestone formations, the targets are usually placed or tied down in the shale formation directly below or above the control bed. The main reason for this is that the shale beds provide a better medium in which to tie the target. If the targets were placed on the limestone, the light color of the limestone beds would blend with the color of the targets. Consequently, if the targets are tied in underlying shales, the arrows will be pointed upslope, the T-target will be upright, and the L and V will be inverted. The opposite will be true if the targets are tied in overlying shales.

The targets are placed intermittently along key beds. Measurements of the geological sections may be made at some target points in the field or are obtained from previous geological reports. When an index bed is covered by overburden, the depth of overburden can be determined at the target point. As each target is laid, the geological contact is noted.



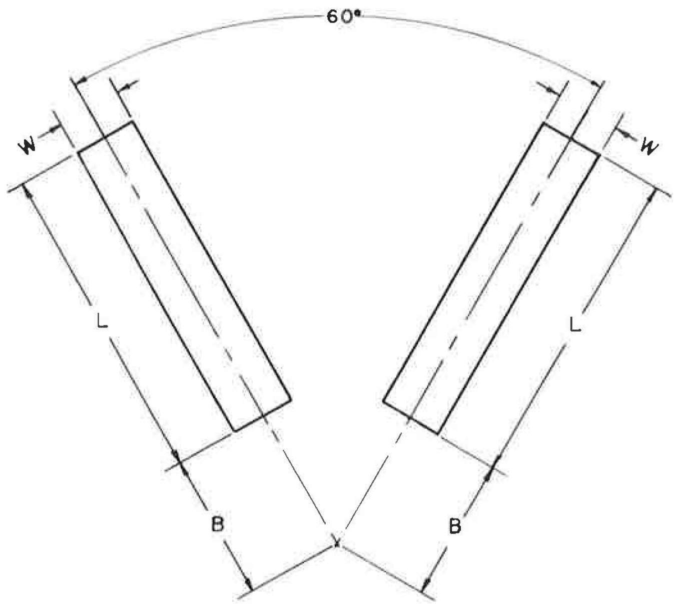
GEOLOGY L TARGET

MINIMUM DIMENSIONS			
FLIGHT HEIGHT	DIMENSION W IN INCHES	DIMENSION L IN FEET	DIMENSION B IN FEET
900	3.00	1.50	2.25
1200	4.00	2.00	3.33
1500	5.00	2.25	3.66
1800	6.00	2.50	4.00

Figure 10.

Many times photogrammetric pass points or points of elevation may be selected to coincide with field geology control points and thus serve two purposes. When this occurs, the normal elevation target is used and a note is made to indicate this point as a geological reference. By sending the geologist to the field with the field control survey crew, much field work can be coordinated and the additional geological control points then require little additional field work.

The use of several types of targets has the distinct advantage of pin-pointing several index horizons in any specific area. The symbol of the target becomes a key for the photographic interpreter and the Kelsh plotter operator as the various horizons are studied and plotted. To illustrate the use of the various targets, a series of geological horizons were located and marked. The area was then photographed. A sample of the photography is shown in Figure 13. This photography can now be used to determine the elevations and local structure of the geology and to determine the effect of the geology as related to the construction, and in this case, maintenance of the existing facility. The lower portion of Figure 13 is a geological column of the same forma-



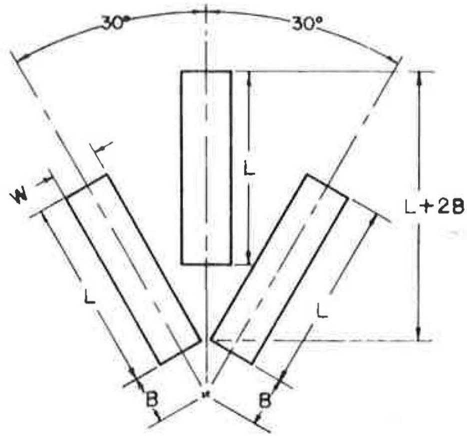
GEOLOGY V TARGET

MINIMUM DIMENSIONS			
FLIGHT HEIGHT	DIMENSION W IN INCHES	DIMENSION L IN FEET	DIMENSION B IN FEET
900	3.00	1.50	1.00
1200	4.00	2.00	1.00
1500	5.00	2.25	1.00
1800	6.00	2.50	1.00

Figure 11.

tion. With this information, the correlation and the characteristics of the various horizons are generally known.

With the use of targets and index beds, geological structural contour maps and geological profiles and cross-sections can be produced with a great deal of accuracy. The field targets produce permanent reference markings on the photography for the photographic interpreter. The inherent characteristics of key beds and the field markings of these and allied beds result in good control and assist in the production of final maps which give not only the topography, contours, and land use but also the geological structural contour map, possible material sources, problem areas caused by ground water, seepage zones, and slide areas, and some indication of the quantity of rock and shale which could be encountered in the area.



GEOLOGY V ARROW TARGET

MINIMUM DIMENSIONS			
FLIGHT HEIGHT	DIMENSION W IN INCHES	DIMENSION L IN FEET	DIMENSION B IN FEET
900	3.00	1.50	1.00
1200	4.00	2.00	1.00
1500	5.00	2.25	1.00
1800	6.00	2.50	1.00

Figure 12.

GEO-ENGINEERING PROBLEMS AND USE OF PHOTOGRAPHIC INTERPRETATION AND KELSH PLOTTER

The use of the Kelsh plotter, photographic interpretation, and field investigations can be applied to a variety of engineering problems. Usually each investigation will not be restricted to one problem, but will extract pertinent information concerning any situation or condition that may exist. With each problem, however, changes in the methods of attack, procedures, and form of report are usually made to fit the needs and to improve the methods. To indicate best some of the procedures used, certain typical examples of the uses made in Kansas of these tools are given.

Feasibility Reports and/or Route Selection

Using small-scale photography, the possible locations of proposed highway improvements are made. This photography is then studied in detail to determine all important information possible to select the proper route or alternatives. After a proposed route or routes have been selected, the centerline of the route is located on the ground. Field crews, besides making initial line measurements, determining property ownership, locating and tying section or property corners, sizing and determining existing structure features, sizing and counting trees and allied functions, also target the line and photogrammetric pass points. Working with the survey crew, a geologist places

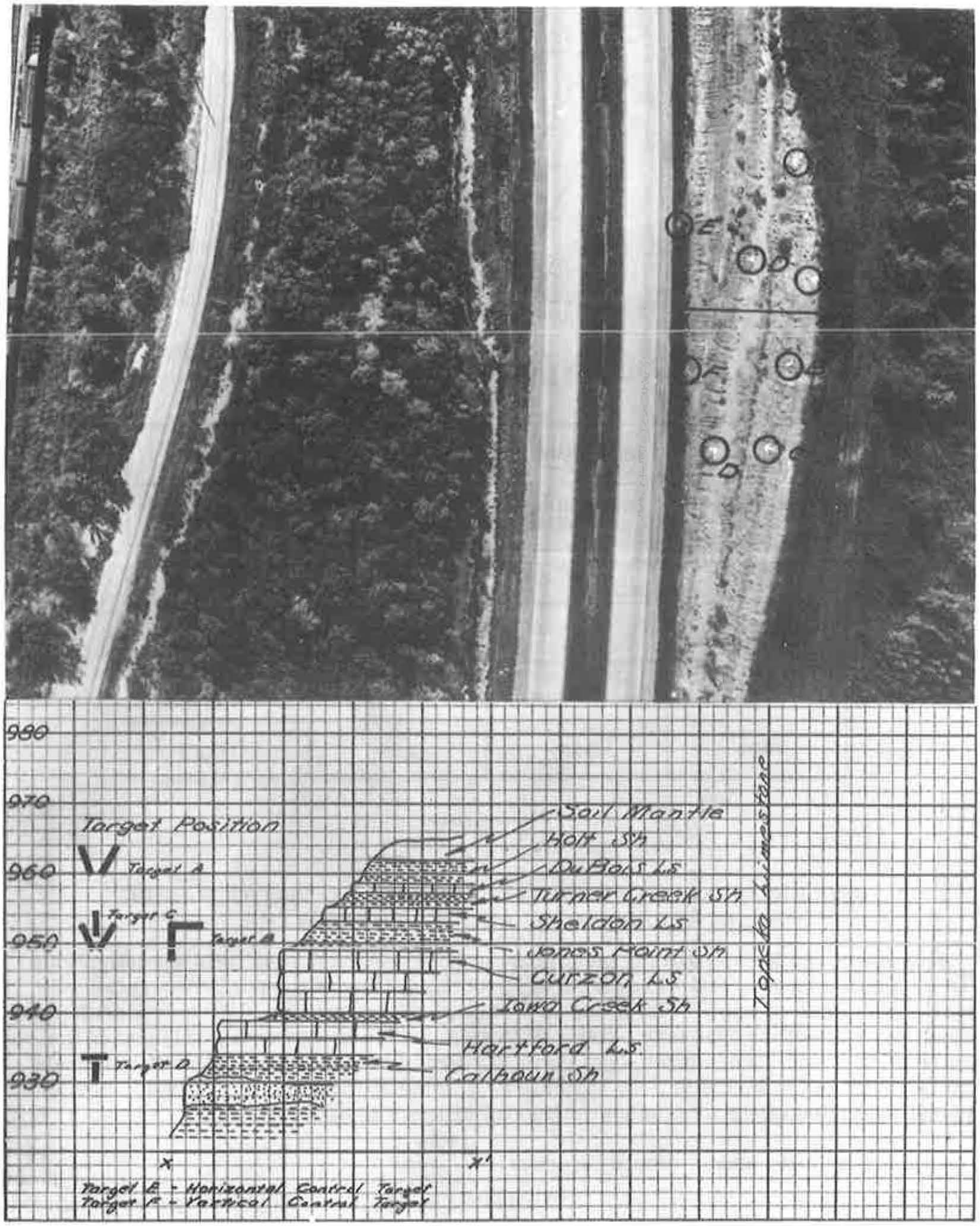


Figure 13. Geology targets on backslope of Highway 24 in Shawnee County, Kans.; lower geological column depicts formations present and corresponding targets.

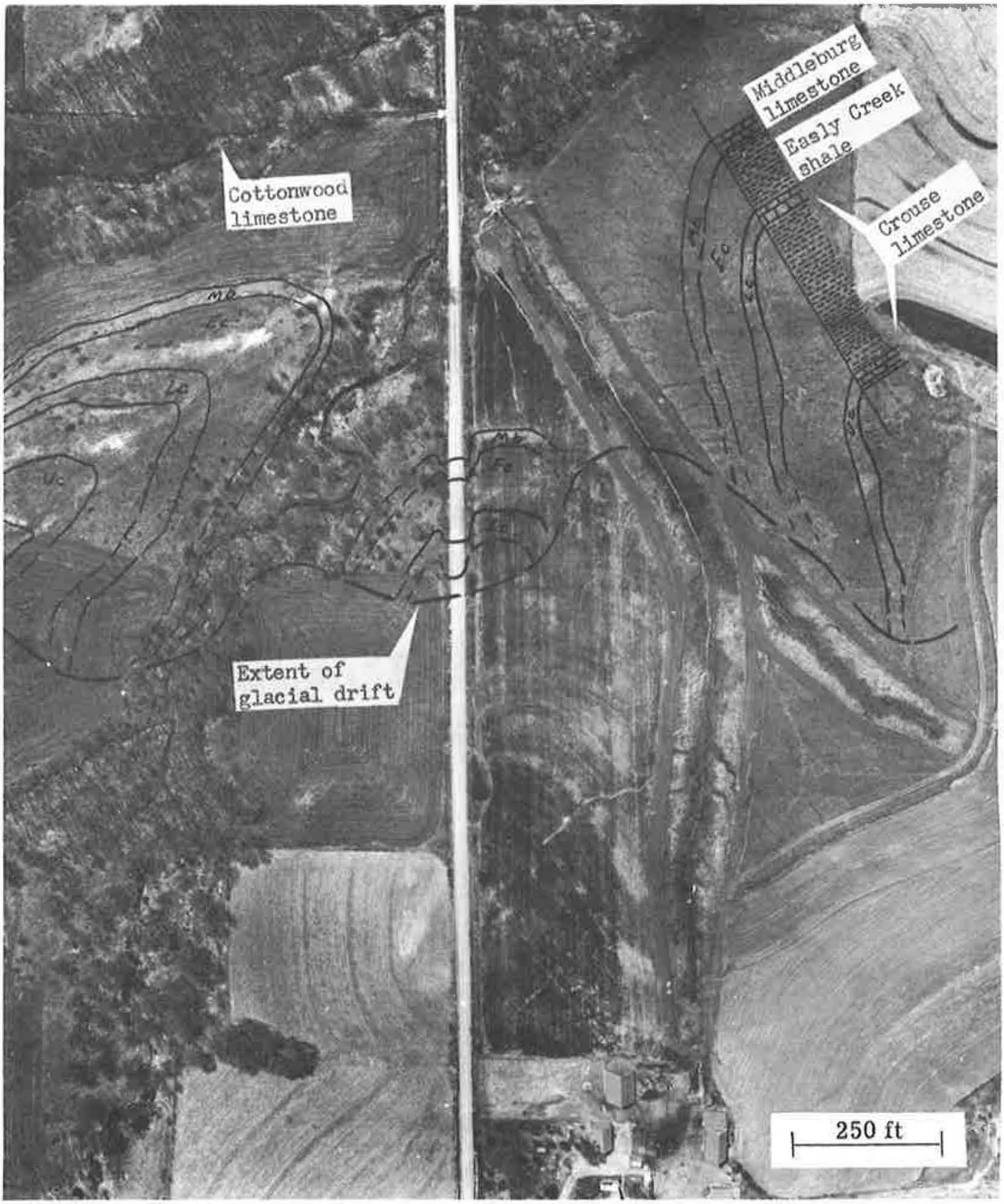


Figure 14. Interbedded limestone and shale capped by glacial drift in Brown County, Kans.; approximate boundary shown was located by use of topographic expression, land use, gully configuration, and tone variation; shows anularity of gully where bedrock is encountered; limestone formations denoted (scale: 1:3,000).

targets on selected geological horizons and usable index beds. If a project is surveyed by normal field survey methods, the areas which, from the initial study, seem to be possible sources of problems are specifically marked by the geologist. The route is then flown and photographed. This photography is used to determine one or more of the following items:

1. Rock and common quantities (estimate).
2. Ground-water conditions and problems.
3. Rights-of-way real estate requirements.
4. Unstable areas.

In April of 1962, a highway improvement was proposed for a portion of North Kansas City, Kans., in Wyandotte County. Route alternatives were selected. One alternative, the longest route, was located to the south of the Wyandotte County Lake and the other was placed north of the lake between the dam site forming the lake and an existing railroad. There was some doubt as to the feasibility of placing a roadway in the latter location and a special investigation was requested.

Existing photography was studied to plan the most feasible and economical way of conducting the investigation. Because of the extreme conditions of the area, it was decided to make the investigation using photogrammetric measurements and photographic interpretation analysis.

The area was characterized by interbedded Pennsylvanian limestones and shales capped with Pleistocene loess. The relief of the area can be described as severe with a 200-ft vertical change in elevation in 600 ft of horizontal distance. Trees, brush, and undergrowth was extremely heavy. The most crucial problems existed in the area around the Wyandotte County Lake.

It was decided to target the area around the dam using vertical control and geology control targets. The photo-geologist accompanied the survey crew in the field and laid all geology targets. A contour map was prepared and geological cross-sections were plotted from elevations and distances measured with the Kelsh plotter. This work and the findings of the investigation were presented to the Special Assignment Engineer in the report contained in Appendix A. This report serves as an example of a typical report presenting information obtained through photographic interpretation and photogrammetric procedures as used in Kansas.

In May 1961, a project was proposed to improve a county road between the small cities of Morrill and Sabetha, Kans., located in Brown County in the northeastern portion of the State. Two alignments were selected and choice of route was based in part on the geo-engineering aspect of each line. The Photogrammetry Section was assigned the problem of providing profiles of each alignment and a preliminary geo-engineering survey.

The geology of the area can be described as interbedded Permian limestone and shales capped in many locals be glacial drift of Pleistocene age. The topography of the area can be described for the most part as hilly.

Targets were laid by the Photogrammetry Section personnel for both alignments. No geology targets were laid because of the existence of identifiable and discernible geology. The photo-geologist spent one day in the field to familiarize himself with ground conditions.

Profiles were plotted for both alignments with measurements taken from the Kelsh plotter. Elevations were taken on selected geological formations. The thickness of the various geological formations were taken from a previous project that was worked in the area. A great deal of interpretation was required to ascertain the bedrock-glacial drift contact. Figure 14 shows bedrock capped with glacial drift along one of the proposed alignments. The geology of each alignment was plotted on the respective profiles. Seep areas were noted and stationed to the centerline. Figure 15 shows a seep area in glacial drift which traverses the proposed centerline.

After all of the interpretation and plotter work was accomplished, a preliminary geo-engineering report was presented to the location engineer. An abridged edition of the actual report pertaining to this problem is presented in Appendix B.

Figure 15. Seep area in glacial drift in Brown County, Kans.; an indication of sand and gravel deposit that may require special attention during field investigation (scale: 1:1,500).

During the early stages of planning Interstate 435 in Kansas City, Johnson County, Kans., the Geology Section of the Kansas Highway Commission was requested to provide information pertaining to the amount of right-of-way that would be required on the preceding project. This information is usually presented after the routine geological field investigation is completed. This type of information would provide the type of

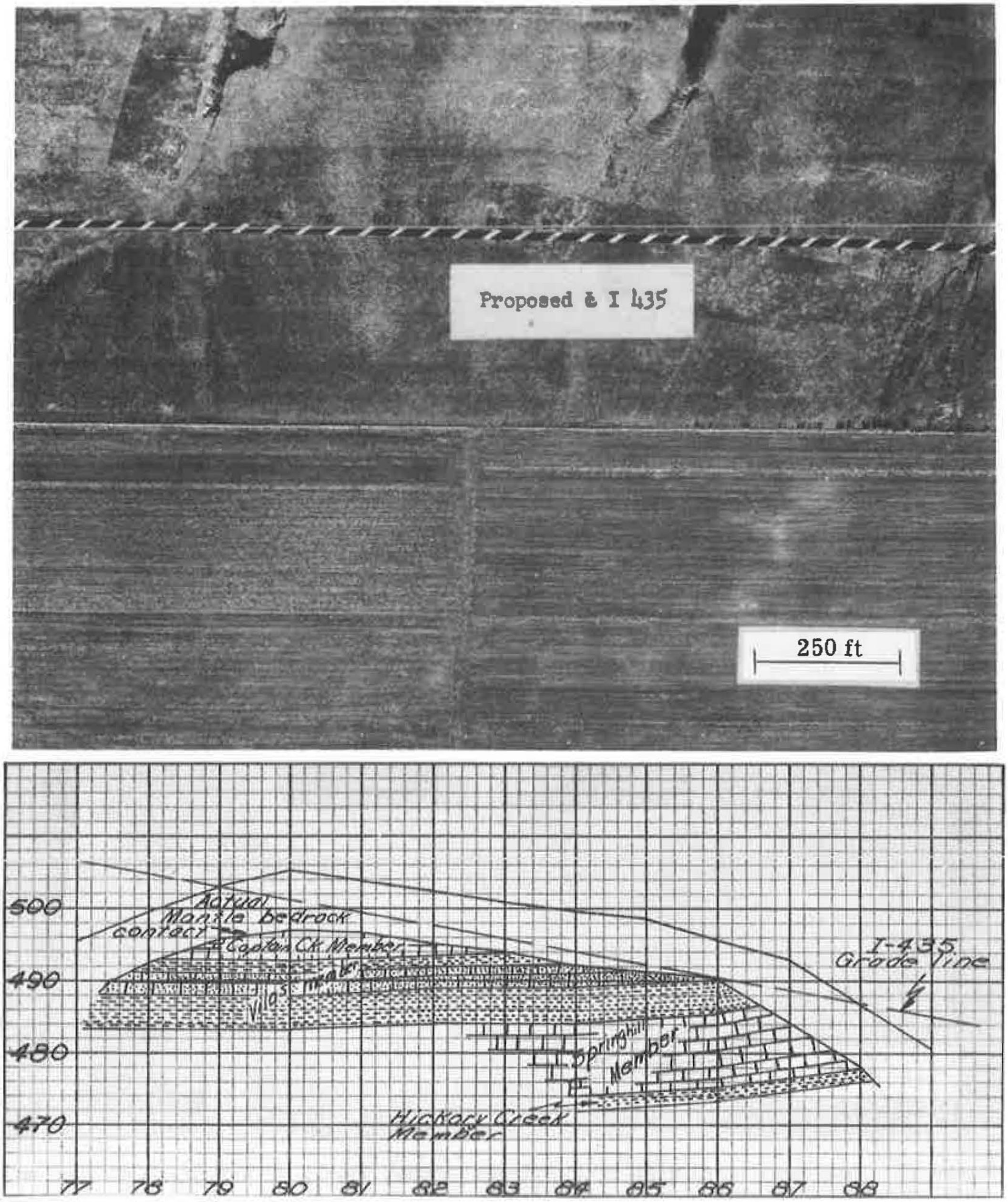


Figure 16. Interstate 435 proposed centerline and profile depicting existing geology and gradeline; photographic analysis indicated only common excavation would be encountered in cut.

material that would be encountered and recommendations as to backslope gradients. This in turn would provide the right-of-way engineer with the width of right-of-way that would be required.

Because this information was requested in advance of the routine field investigation, a photo-geologist was requested to obtain this information through photographic interpretation procedures.

The area was characterized by interbedded limestones and shales capped with a varying thickness of transported material. The proposed alignment traverses open fields, wooded areas, and suburban housing developments.

The centerline of the proposed project was plotted on existing photography. Photography with a scale of 1:3,000 and 1:12,000 was used for interpretation purposes. Topographic expression, gully analysis, land use, photographic tone, and knowledge of the local area were used to complete the investigation. Figure 16 shows a portion of the centerline on an aerial photograph. The material was predicted to only a depth that would cover the gradeline elevation. The lower portion of Figure 16 shows the results of the investigation and the actual geological profile as plotted from the subsequent geological field investigation.

SLIDE AREA INVESTIGATIONS

From the study of small-scale photography and from a knowledge of the characteristics of certain geological formations and the ground-water conditions, slide areas or the possibility of slide areas can be ascertained. Prevailing conditions may keep certain forces in equilibrium and slides may not exist in some areas while these same areas may be subjected to slides when large cuts are developed through certain geological horizons. When slides are apparent or when conditions exist that indicate possible slide problems, the areas are further studied from lower controlled photography.

Slides have also developed along existing construction. These areas have also been assigned for study by photogrammetry and photographic interpretation using the Kelsh plotter for the maintenance studies needed for the stabilization of such areas. The methods of control, the factors of detection and maintenance, and the use of Kelsh measurements are best discussed by the following examples.

Detection of Slides

In the spring of 1959 the preliminary field data for Interstate 70 west of Salina, Kans., was being collected. During this process the final alignment of the proposed project was being made in Ellsworth County, Kans. Once the alignment had been established, the geology field crews began their investigations. Several severe slides were encountered in the early part of their investigations.

The geology of the area consisted of Cretaceous chalky limestone and shales underlain by Graneros shale, an unctuous clayey shale that has a high percentage of montmorillonite. The Graneros shale is underlain by the Dakota formation. The fencepost limestone index bed mentioned previously capped most of the ridges and was used extensively throughout the investigation as a reference bed. Most of the slides occurred in the Graneros shale. When this formation forms the steep sided canyons and escarpments, numerous slides occur as the result of gravity and ground-water action. A few slides also occur in the underlying Dakota formation.

To get a complete picture of the relationship of the proposed centerline and slide areas in this area, aerial photographs were used to detect and map all slides, establish the centerline proximity to these slides and map the geological formation in which the slides were occurring.

Topographic expression, photographic tone, and a knowledge of the geology of the area were used to complete the photographic interpretation investigation.

The result of this investigation is shown in Figure 17 which depicts a portion of the realignment which subsequently took place. Figure 18 is a stereogram of a portion of the area that was investigated. The new alignment which was selected on the basis of these findings avoided the more severe areas and in most cases approached the Graneros shale escarpment at right angles to avoid any slide slope situations.

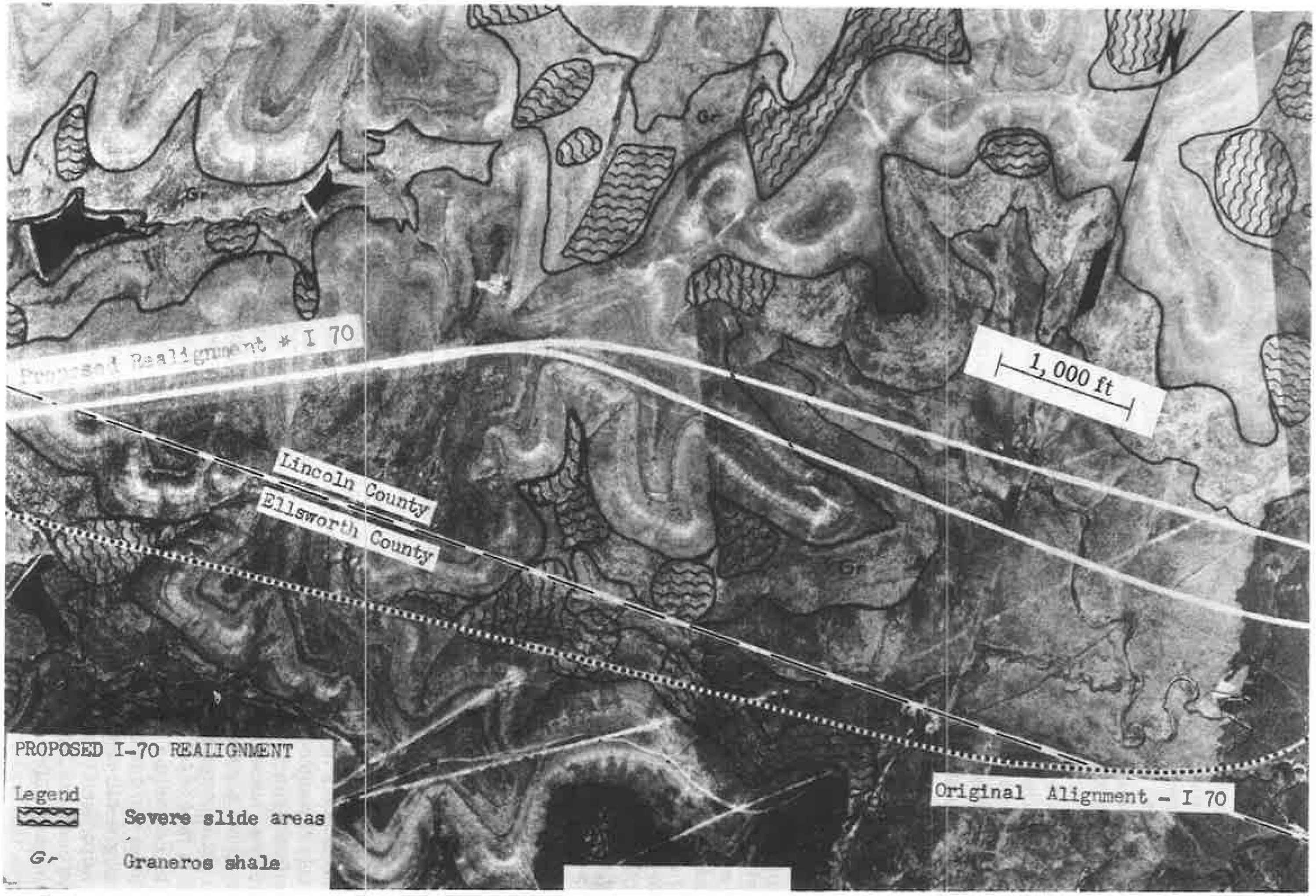

Proposed Realignment # I 70
1,000 ft
Gr
Lincoln County
Ellsworth County
Original Alignment - I 70
PROPOSED I-70 REALIGNMENT
Legend
Severe slide areas
Gr
Graneros shale

Figure 17.

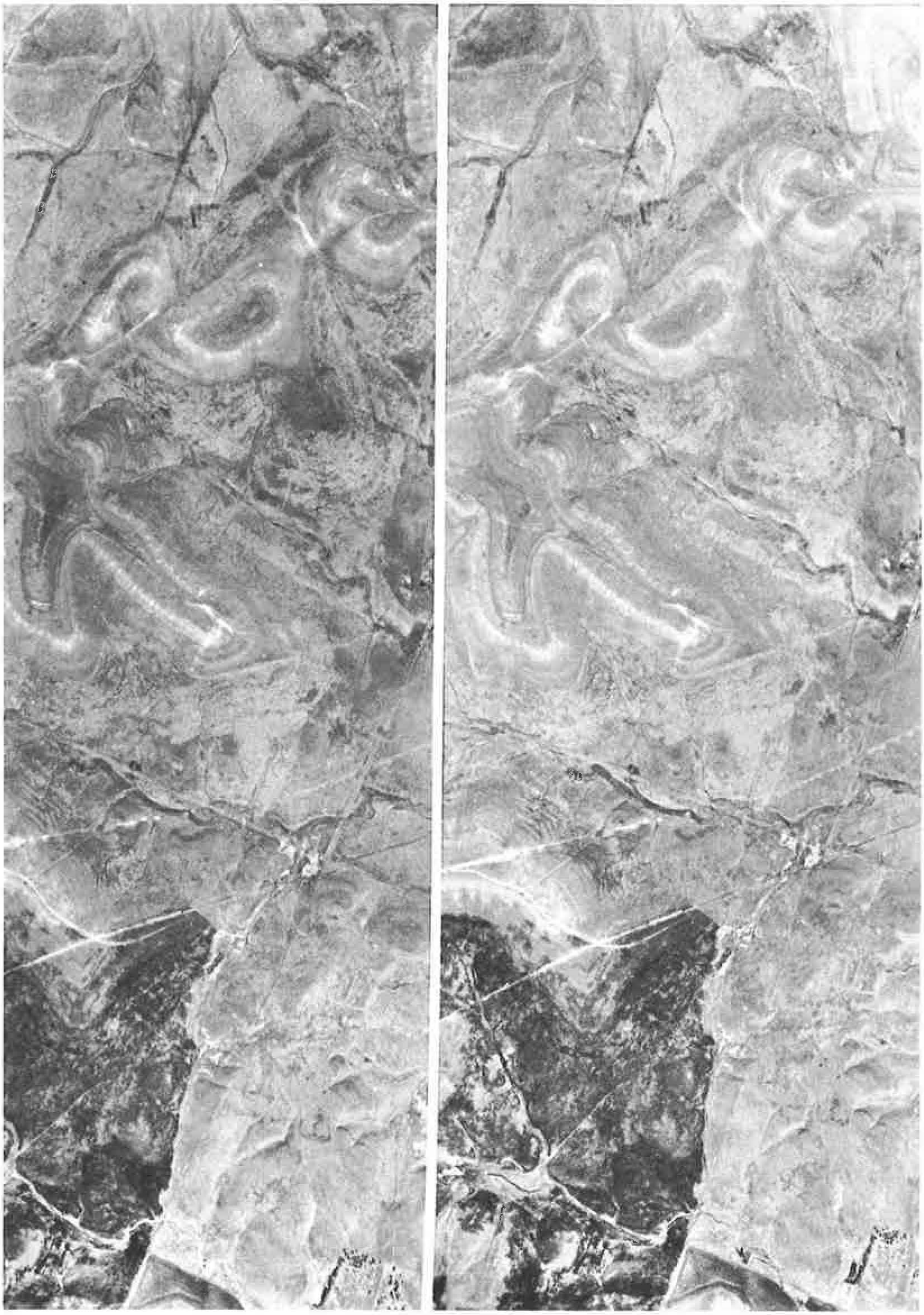


Figure 18. Stereogram of Greenhorn limestone and Graneros shale in Ellsworth County, Kans.; shows many slides that occur in the Graneros shale.

Slide Analysis

In July 1960, a slide occurred next to the Cedar Bluff Reservoir dam on State Highway 147 in Trego County, Kans. The Geology Section was requested by the Maintenance Department to investigate the slide and to provide information concerning the cause and to make recommendations as to the prevention of further slides in the area.

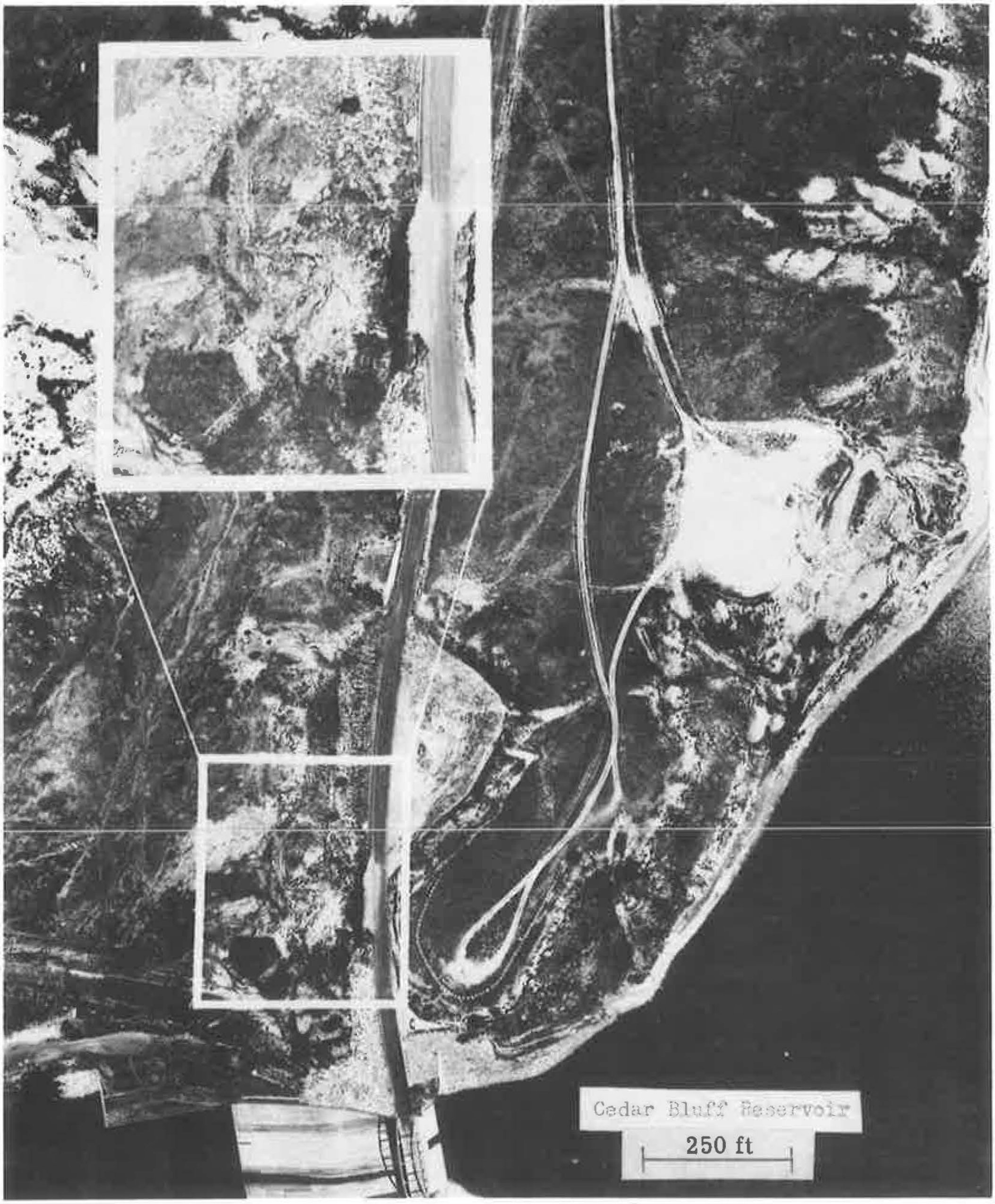


Figure 19. Cedar Bluff Reservoir in Trego County, Kans.; shows road slide on Kans. 147 (scale: 1:3,000).

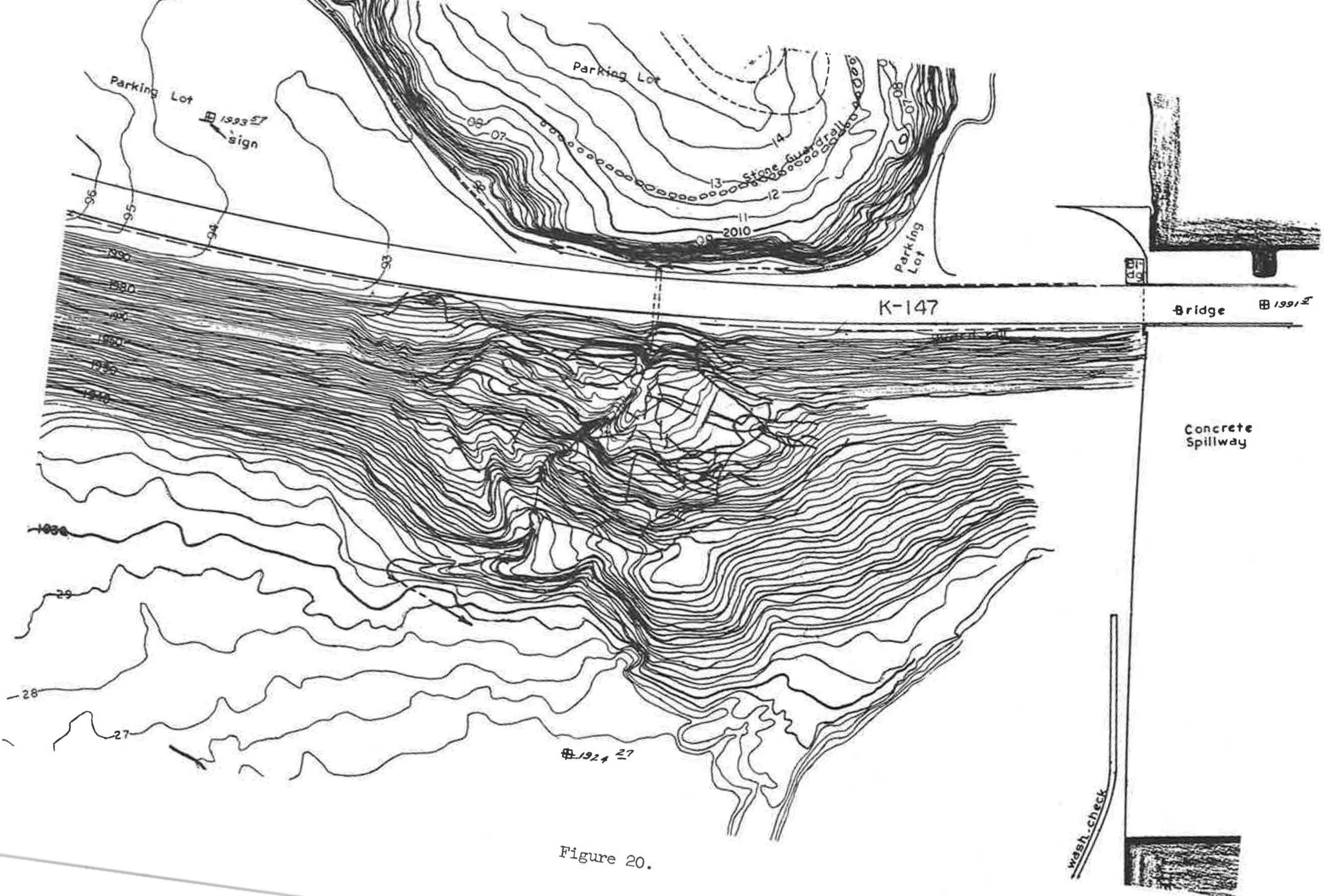

Parking Lot
sign
Parking Lot
Stone Guardrail
Parking Lot
K-147
Bridge
Concrete Spillway
wash check

Figure 20.

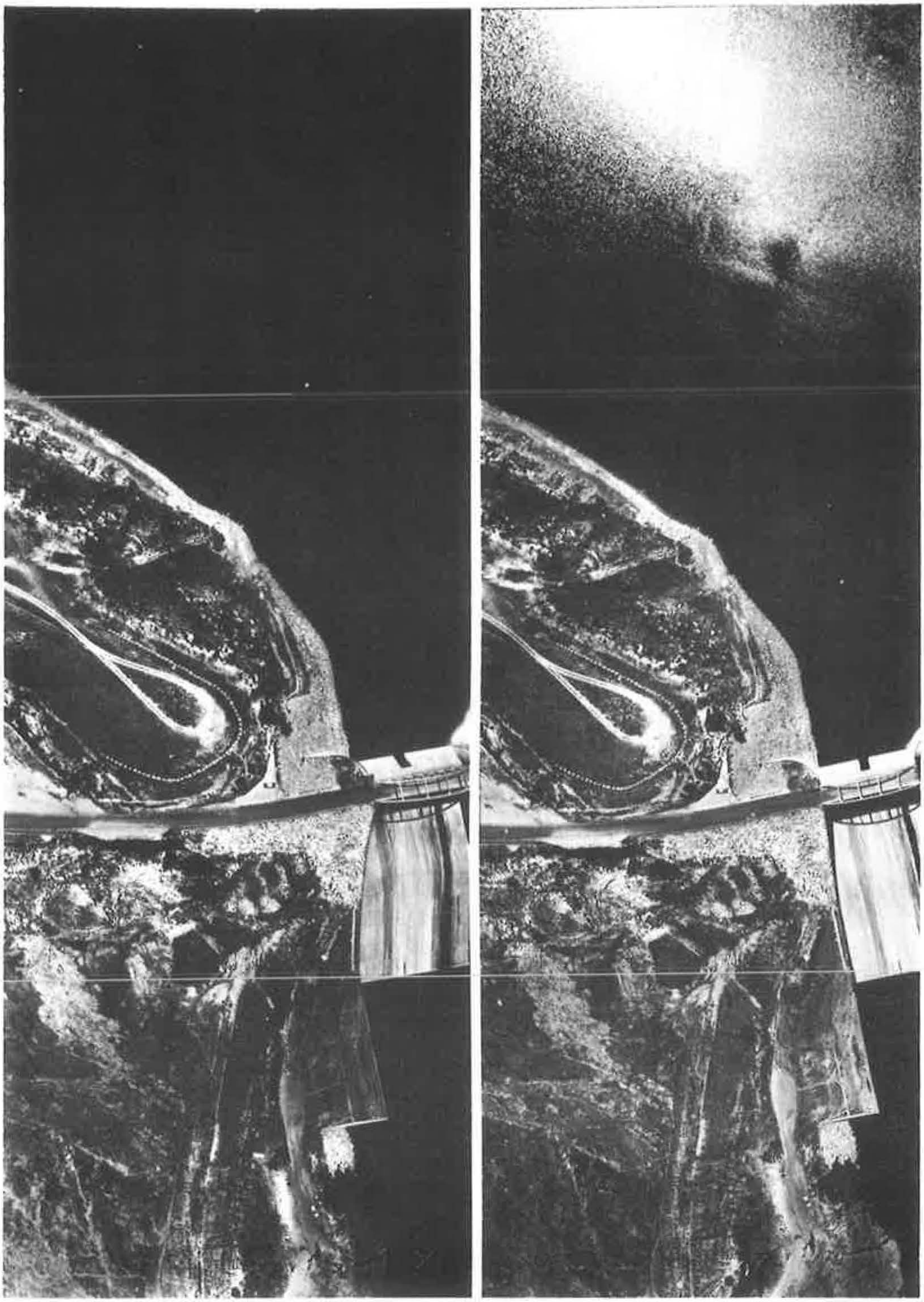


Figure 21. Stereogram of slide area along Kans. 147 in Trego County; contour map of this area produced on Kelsh plotter depicting location and elevations of slide planes.

The first step in such an investigation is the compilation of a contour map of the slide. This is normally compiled in the field.

At the request of the chief geologist, the Photogrammetry Section for the first time produced a contour map of a slide area.

Photo-control points were selected on existing photography and sufficient control obtained. No geology was mapped because the slide took place in one formation.

A photo-geologist and plotter operator mapped not only the slide area, but much of the surrounding area. This proved to be of great value in the final analysis because the amount of runoff of the immediate drainage area was the key to the cause of the slide. All slide planes were detected and mapped and other potential slides in the immediate area were indicated. Figure 19 is an aerial photograph of the area mapped and Figure 20 shows a portion of the contour map produced from this endeavor. Figure 21 is a stereogram of the slide area. This work was accomplished in one-fourth the time that would be required for a field crew and produced a map of larger scale which covered four times the area normally obtained through field investigations.

This information was presented to the chief geologist for further analysis.

HYDRAULIC AND HYDROGRAPHIC INVESTIGATIONS

Problems involving hydraulic and hydrographic principles occur in most any area where rainfall exists. These problems may be a part of other investigations or may be considered as the principal problem for which a solution is sought. The procedures here again vary with the problem, but measurements made with the Kelsh plotter coupled with photographic interpretation has resulted in the collection of data that allowed the solution to many hydraulic and hydrographic problems. Several specific examples again will show the use of the photogrammetric tools in the solutions of such problems as overflow problems, stream meander and erosion, silting, and drainage areas.

In the spring of 1962, the assistant bridge engineer of the Kansas Highway Commission assigned the problem of analyzing the cause and the extent of stream degradation on Turkey Creek at the crossing of State Highway 32 in Wyandotte County, Kans. In the early fall of 1961, this stream had scoured to such a point that the highway bridge had been undermined and the subsequent collapse of the structure resulted. Further sloughing of the stream banks occurred upstream adjacent to farmland after the structure collapsed. Many of the local residents felt that the Kansas Highway Commission was at fault and was liable for the loss of the farmland. This investigation was requested to determine the reasons for such stream action.

Five sets of aerial photographs dated 1941, 1954, 1959, 1961, and 1962 were used to study the stream activities for the past 21 years. The Wyandotte County Turkey Creek report depicts the stream configuration for each of these years. Figure 22 shows the highway structure condition immediately after the collapse. Appendix C gives an abridged edition of the report presented to the Bridge Section.

In the summer of 1962, a new alignment was being proposed for State Highway 32 near Bonner Springs, Wyandotte County, Kans. The new alignment crossed Wolf Creek two times within a few thousand feet. Figure 23 shows this relationship. To avoid the construction of two bridges a channel change is proposed. The assistant bridge engineer requested a photo analysis of the area to ascertain the probable damage that would be incurred on bridge structures in the area and surrounding farmland if the channel change was completed.

Two sets of photography dated 1941 and 1962 were used to study the stream migration pattern for the past 21 years. A contour map of the area in question was compiled on the Kelsh plotter and the photo-interpreter obtained specific elevations on structures, stream bed and surrounding terrain that might be affected by the channel change. An abridged edition of the report which was submitted to the Bridge Section is presented in Appendix D.

In the spring of 1959, the replacement of a structure over Bullard Creek in Clark County, Kans., prompted a study of the drainage area involved. Bullard Creek heads on the bank of the Cimarron River and highwater of the river flowed into the creek.

The northerly bank of the river was targeted and elevations of the targets were measured. Distances between targets were also measured to provide horizontal scale. A contour map was produced with hundreds of spot elevations. Although this map was being compiled by use of the Kelsh plotter, the photographic interpreter worked with the plotter operator to determine elevations at specific points in the area. Using the information from the Kelsh plotter and a series of photography covering the years 1937

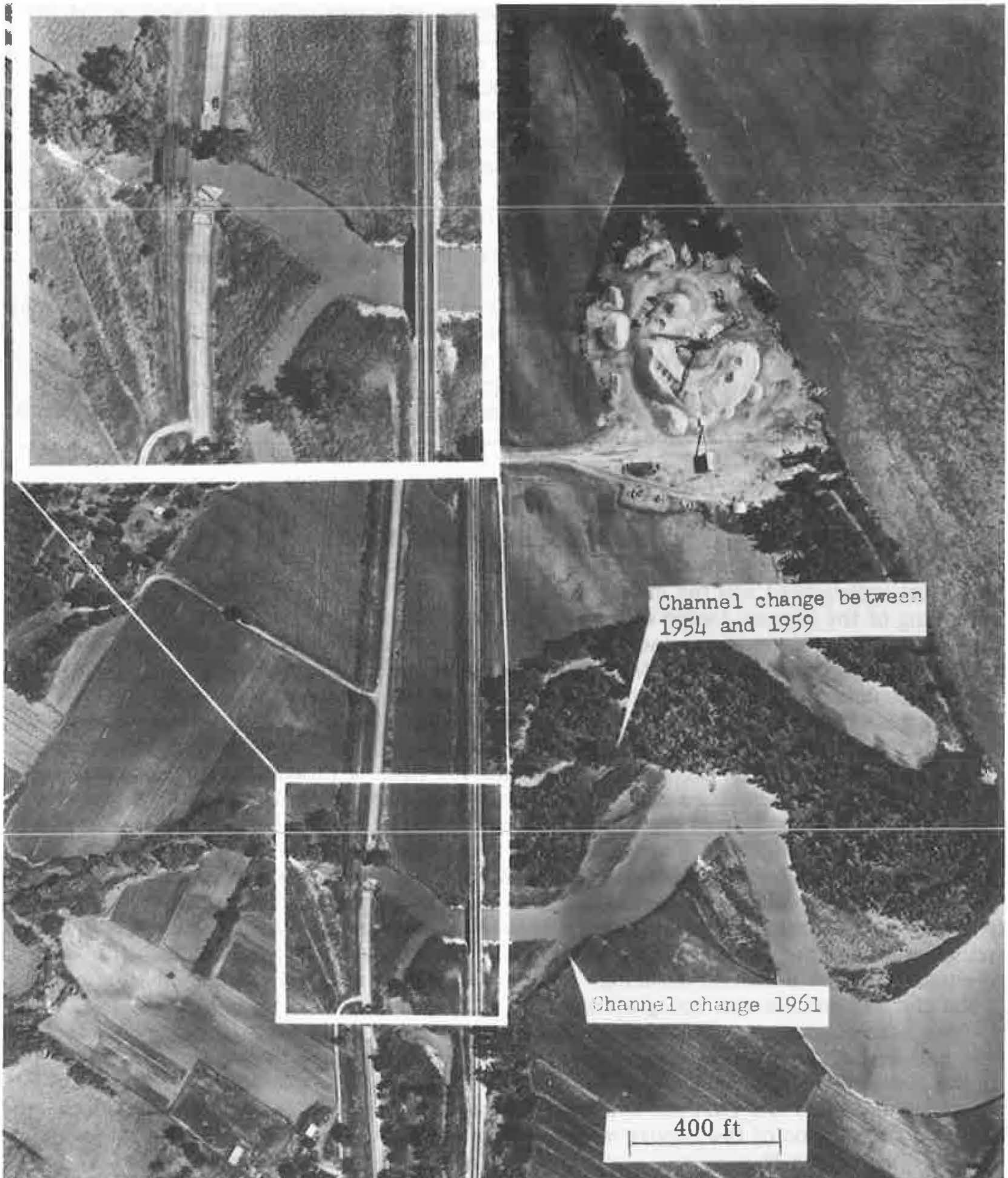


Figure 22. Bridge collapse as result of stream degradation on Kans. 32 in Wyandotte County (scale: 1:4,800).

through 1961, a stream migration study was completed and reported through a series of overlays. A photographic mosaic and a contour map were used in the presentation of the study.

Some of the drainage area under investigation included a small portion of the State of Oklahoma. No infiltration data were available to the Bridge Section to compute final

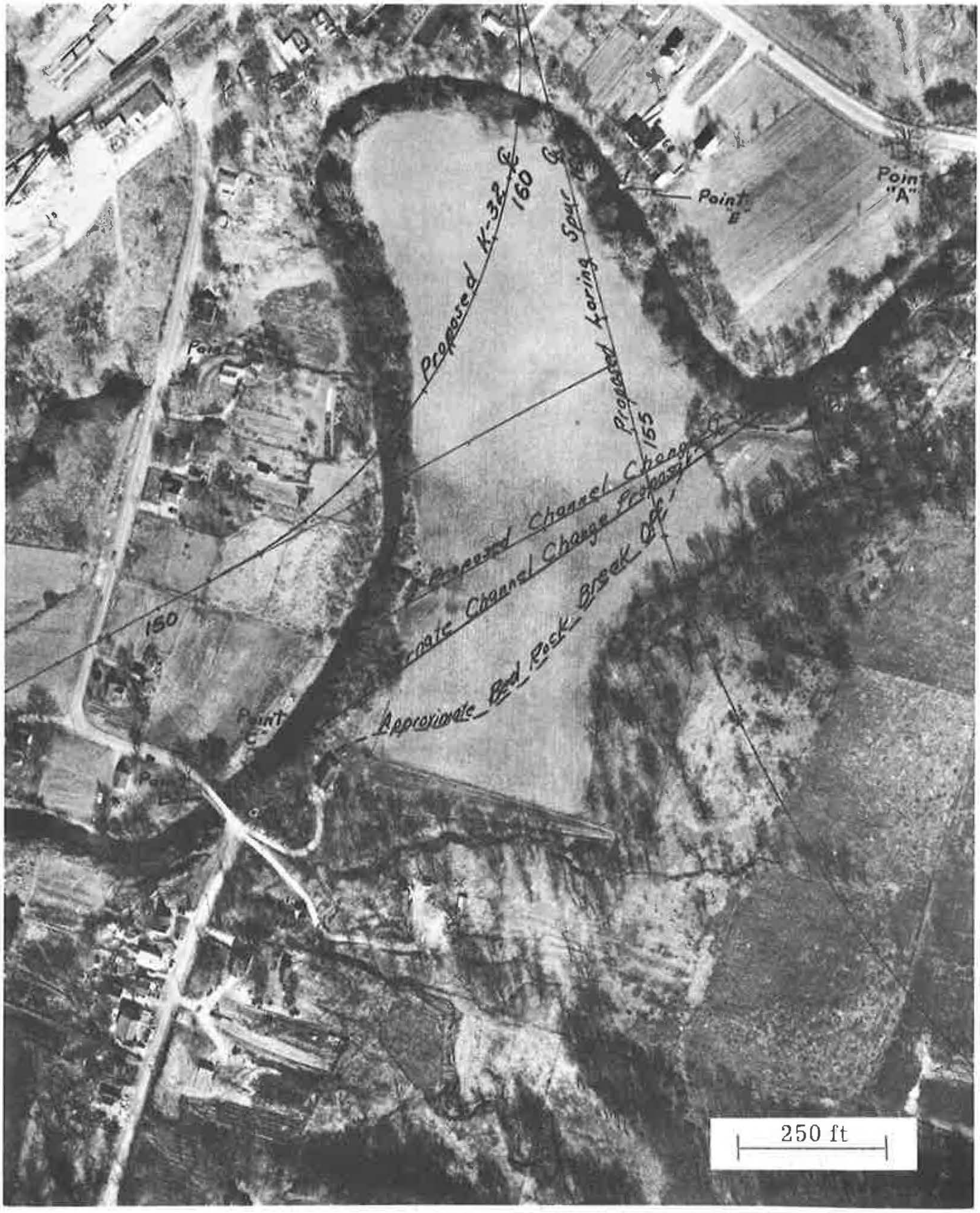


Figure 23. Proposed channel change on Wolf Creek in Wyandotte County, Kans. (scale: 1:3,000).

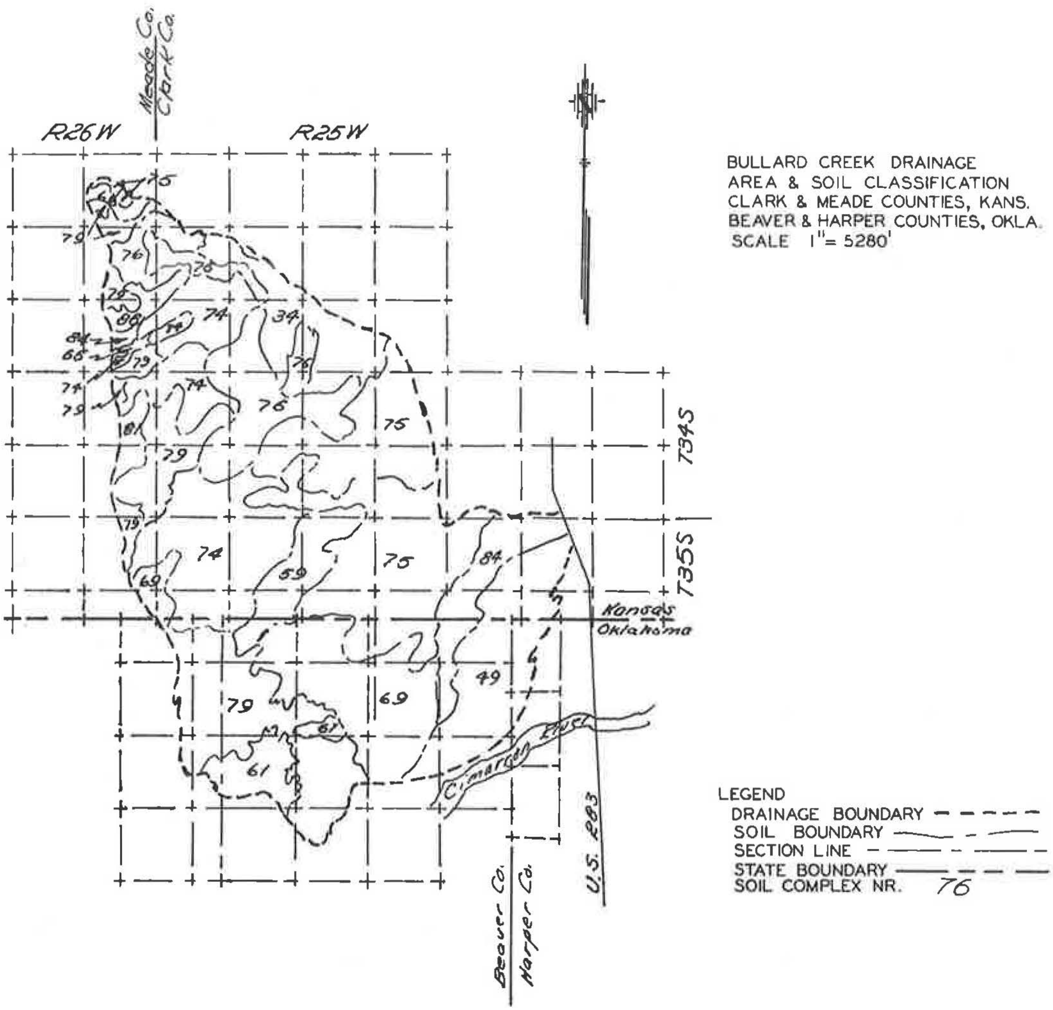


Figure 24.

run-off data. The photographic interpreter by using known infiltration data available in Kansas, mapped the soils in Oklahoma using the same type of classification system. Figure 24 shows a small-scale version of the completed soils map.

From the report of this study, it was obvious that overflow from the river had affected the amount of water carried by Bullard Creek on many occasions. It was also apparent that if the Cimarron River was to ever occupy the Bullard Creek channel, the sand carried by the Cimarron River would provide a source of sand which when transported by winds would be a threat to the nearby town of Englewood and surrounding farmland.

The USGS used the data thus reported to determine the amount of overflow expected for several cycles of time. Water run-off from the drainage area of Bullard Creek plus the overflow of the Cimarron River were combined to determine better the cross-section required for stream flow and in turn supplied the data to determine the size of the new bridge structure. This data also pointed to the possible reconstruction of a dike along the Cimarron to prevent overflow into the creek.

During the past two decades a series of dams have been built on some major Kansas streams by the Army Corps of Engineers and the Bureau of Reclamation. On many of

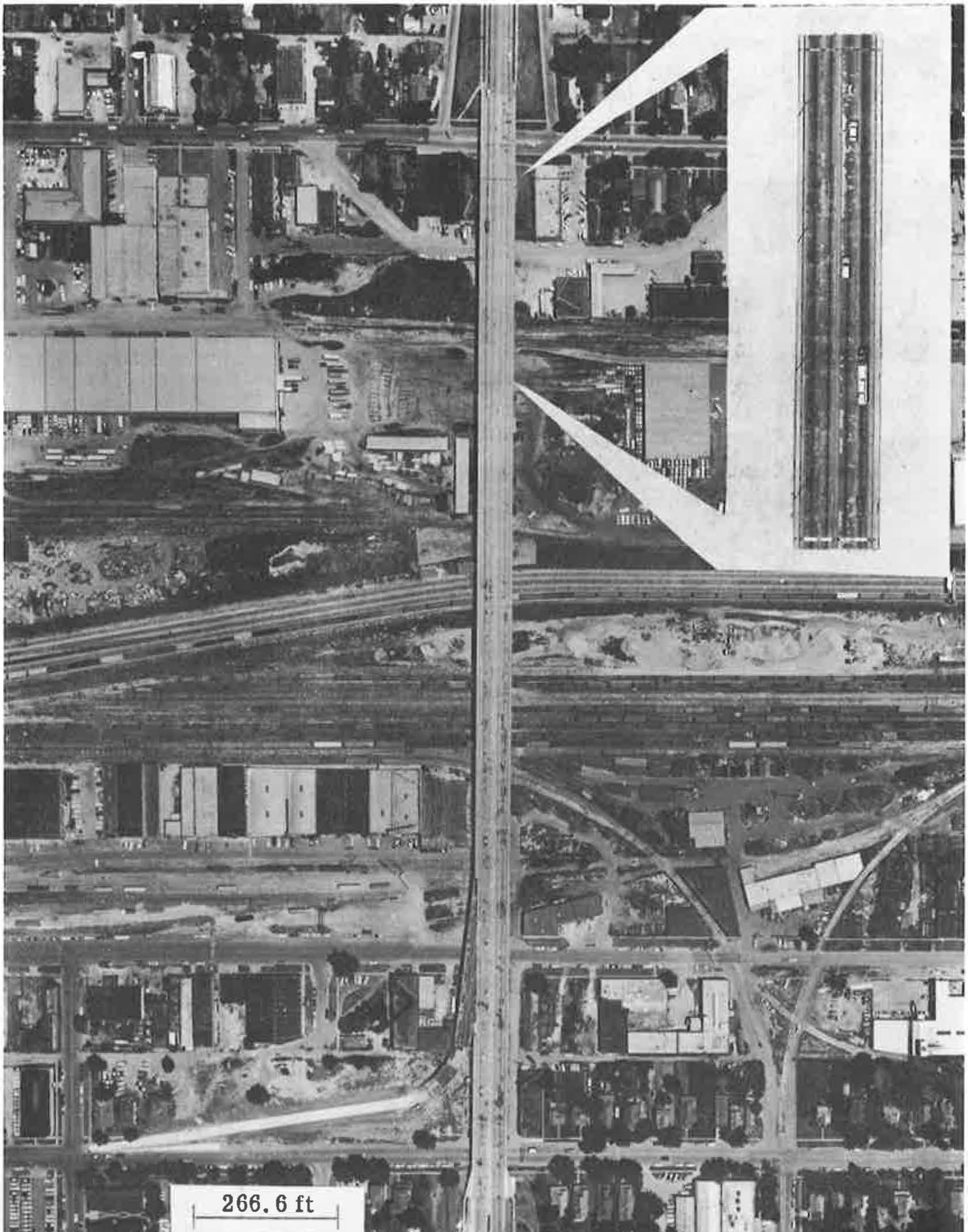


Figure 25. Kellogg Street viaduct in Wichita, Kans. (scale: 1:3,200).

these streams, the Highway Commission of Kansas has constructed and maintained bridges. Many of these bridges are located upstream from the dam of the reservoir. The silting of the channels at the bridge crossing have caused some concern. To keep abreast of the problem, aerial photography is being taken of all such areas and contour maps are to be compiled with the Kelsh plotter. Existing photography taken in past years is being studied by a photographic interpreter to determine the extent and rate of silting. This project is in the initial stages and will continue for many years.

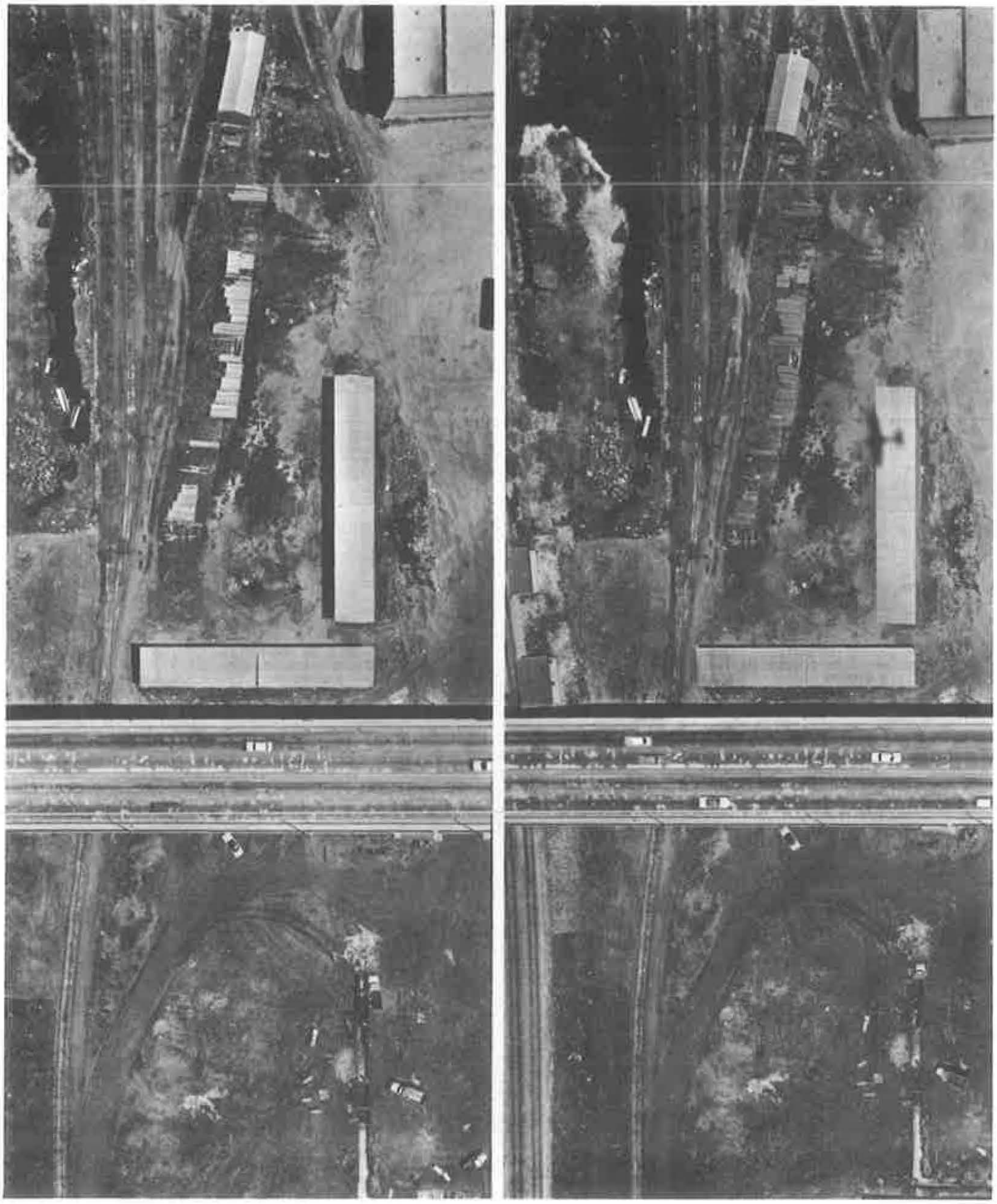


Figure 26.

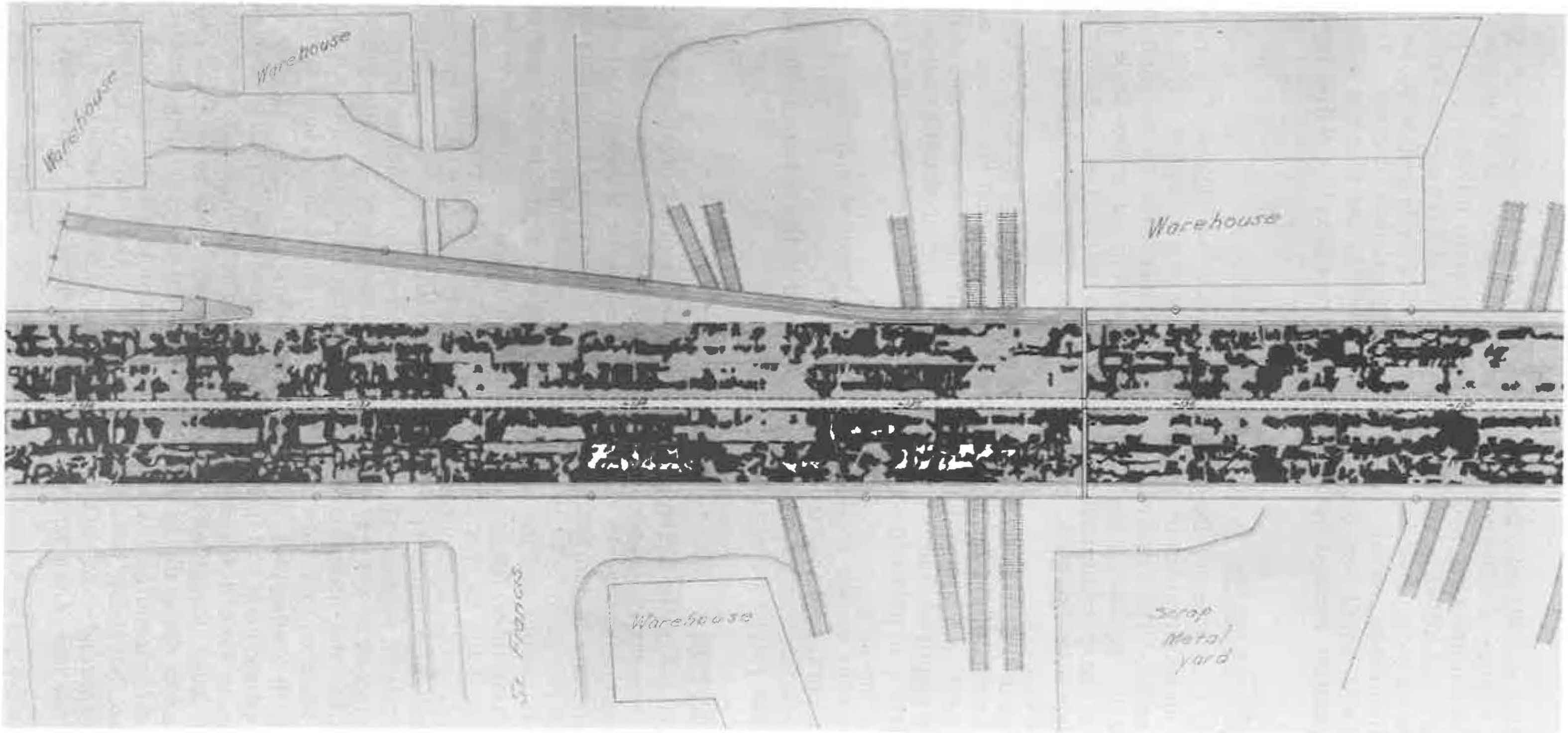


Figure 27. Stereogram of Kellogg Street viaduct deck; shows intricate deck pattern resulting from two generations of patches.

CONDITION SURVEYS

The Kelsh plotter and the information obtained through its use also played a part in several condition studies of construction projects. This tool, it is believed, would be cumbersome to use on projects involving the study of many miles of pavement. Bridges, intersections, and allied areas can, however, be studied as specific problems by this method. When a study covering several years of time is required, permanent control can be established and the area reflown at the desired interval. The study can thus be continued with small cost for control. To see the use that has been made of the method for condition surveys better, the following example and discussion are presented.

Bridge Deck Conditions Survey

In August 1961, the Research Department of the Kansas Highway Commission authorized the use of an epoxy-resin to improve the deck of a bridge in Wichita, Kans., on an experimental basis. The research engineer was interested in the condition of the original bridge deck. By having the condition of the original bridge deck available, new failures in the epoxy-resin could be traced as to origin; i.e., whether failures occurred on the original bridge deck, on the first generation of patches or on the second generation of patches.

To obtain a map of the original deck that could be overlain by later traces, the map had to be exact. The combination of the differences of ground elevations, aerial photography flight height, and stretching of the foils could give erroneous results. To obtain the exactness required, the mapping was accomplished on the Kelsh plotter. Permanent field control was obtained which can be used on future mapping projects of the same deck when necessary.

Figure 25 shows the bridge deck before the epoxy-resin was applied. Figure 26 is a stereogram of a portion of the structure (Fig. 27).

Appendix E gives information which was submitted to the research engineer along with the map for his reference and study.

Road Conditions Surveys

A very common use of the Kelsh plotter is that of mapping existing road interchanges. Construction changes, traffic analysis, accident rate studies, maintenance requirements and many other facets connected with highways and especially with intersections are continually in demand. Photography of certain intersections with permanent control can serve as a continuous study of any particular road intersection.

Changes in construction and the loss of old plans often initiate the first request for a new map of existing interchanges. As these requests were honored by the Photogrammetry Section of the Kansas Highway Commission, the usefulness of the maps and the allied photography became increasingly apparent. Photographic interpretation began to be employed and soon more information beyond the contour and topographic map was extracted from this photography. When the design and construction of highway facilities are conducted by several authorities such as cities, counties, turnpike authorities, and the like, the designs and engineering that have gone into any particular interchange may often be found at several sources. To combine such information is often best done by the remapping of the interchanges.

The Planning Department has found the photography used for this purpose a very handy tool in keeping the official maps up to date. The photography presents an accurate record of the interchange area on a specific date. This record has been a useful tool in the revision of maps and in the reporting of construction progress.

Photographic interpretation has not moved forward as fast in this field as in some of the allied areas, but it has been tried with success and will with time become another tool in determining road conditions on a local basis and coupled with the mapping that comes from the use of the Kelsh plotter will also present more information cheaper and faster.

ADVANTAGES AND DISADVANTAGES OF PROCEDURES

The advantages and disadvantages of the procedures and techniques discussed in this report do not pertain to any one particular job. The different factors affecting the reliability, the ease with which a project can be accomplished and the cost of each project will vary from project to project. Different problems are encountered on different projects and are solved in different ways. The most efficient method of operation or procedure herein reported may not be the best method because the techniques and methods are a continuously changing operation regardless of the amount of experience that has been accumulated by individuals or by the using organization.

The advantages of these procedures can best be described in the speed of accomplishment and the type of information that is obtained. In many instances, the information obtained can not be duplicated in the field. Stream study over a period of years can not be conducted in the field. This is a good example of the permanency with which an aerial photograph holds a record of the conditions of a particular item or area. Older aerial photography can easily be obtained from different Federal agencies.

Other information that is beneficial and sometimes required for the highway engineer can be acquired by routine field methods but would not be economically feasible. The survey of the bridge deck mentioned previously and the obtaining of preliminary geological information in a very inaccessible area serve as good examples. It took the plotter operator and photographic interpreter nine days to complete the reported bridge survey. It would require months, and maybe years, for a survey crew to obtain the same information and plot it on a base sheet.

Another big advantage of these procedures is that the analysis of the problem can take place during the time that the information is being compiled. If additional information is needed or more elevations required, this can be accomplished in a matter of minutes. In many cases complete problem areas are observed and studied or measured at the same time.

There is no doubt that engineers in Kansas now have information available that was unobtainable in prior years or was too expensive to acquire. This information in many cases helps to make better decisions which are substantiated by accurate findings and which may save millions of dollars in form of liability suits, and maintenance and construction costs.

The disadvantages of these procedures are those that are probably also encountered on other photogrammetric and photographic interpretation endeavors. The need of photography, the weather required for flying photography, the seasonal requirements for specific photographs, and field control requirements are all problems that must be accepted but are considered a part of the procedures just as chaining is considered a part of routine field surveying. Some disadvantages are inherent to these problems and involve natural covers, such as vegetation and soil mantle.

Areas of dense vegetation will eliminate or limit the number of elevation points that can be measured accurately. Soil mantle, whether transported or residual, also hampers the accuracy and the extent of detailed geological interpretation. Additional ground work is sometimes required. This is true also in areas where the geology is erratic.

In many cases, the lack of qualified personnel or, in many cases, interested personnel is a problem. Usually, with some formal training and with an interest in the procedures, geologist, soil scientists, and civil engineers can obtain good results from aerial photographic interpretation.

One of the big problems that any organization will encounter during the initial use of any new procedure or system is the lack of understanding of the new system. The people who are performing the work and who are using the results of the work should know the capabilities and the limitations of the system or procedures involved. The personnel who are performing the work should know what can be accomplished and how reliable the results are to be able to determine what projects can be worked. The personnel who request the work should know if the results will meet all requirements of the investigation.

Appendix A

WYANDOTTE COUNTY - K-5 REPORT

MAY 1962

MEMORANDUM TO: MR. H. O. REED, ENGINEER OF DESIGN
FROM: Mr. Virgil A. Burgat, Chief Geologist
By Alvis H. Stallard, Geologist I
Walter Fredericksen, Regional Geologist
SUBJECT: Preliminary Geology Report
Project No. 5-105 U-087-1 (3)
Wyandotte County

INTRODUCTION

The purpose of this report is to present a preliminary geo-engineering analysis of a prospective centerline of an alternate route of proposed route K-5 in Wyandotte County, Kansas. The information contained herein was compiled by photographic interpretation and by photogrammetric and field observations. A portion of the area under investigation was mapped on the Kelsh plotter at a scale of 50 feet to one inch with a 2-foot contour interval. This area is representative of the more severe areas that will be encountered on this project. Geological cross sections were plotted illustrating the geology and accompanying geo-engineering problems of the area. Only general terms are used in describing the problem areas since the magnitude of each problem will vary with the designed location of centerline. This report can best be utilized with the attached cross sections and diagrams.

The area under investigation is located in the S 1/2 Section 18 and NW 1/4 Section 20, T 10 S, R 24 E, in Wyandotte County. The prospective centerline runs from North 79th Street to present K-5 alongside the Missouri Pacific Railroad right of way and the existing county road in the area. The enclosed photographic mosaic depicts the county road, the railroad, and specific areas that were studied and mapped. [The size of the photographic mosaic prevents its reproduction in this paper. Figure 28 has been substituted which gives in part the information shown on the photographic mosaic.]

The geological units that will be encountered, if construction takes place in this area, are the Cherryvale Formation, Drum Limestone, Chanute Shale, Iola Limestone, Lane Shale, Argentine-Frisbie Limestone, Island Creek Shale, Farley Limestone, Bonner Springs Shale, and the Plattsburg Limestone. All of these geological units belong to the Pennsylvanian System. They are overlain by varying thicknesses of loess of Pleistocene Age.

The direction of drainage is to the north into the Missouri River Valley. Total relief of the area is 200 feet. An apparent dip of the geological units of 1-foot per 60 feet to the east was observed along the face of the valley wall.

Numerous springs were observed along the valley wall and will be discussed in detail in the geo-engineering aspects of this report.

GEO-ENGINEERING ASPECTS

The following presents information concerning different geo-engineering facets that should be considered.

Wyandotte County Lake Dam

This structure is included in the report due to its proximity to the proposed project. The northwestern abutment of the dam is included in the portion of the area that was mapped and cross section CC' [Figs. 29, 30 and 31] depicts the geology of this abutment. The dam can be observed in areas 2 and 3. [Fig. 28]

The dam was first constructed in 1936. Before construction was completed the central portion of the dam failed. This failure took place because of the following factors.

The dam was constructed on alluvial clays approximately 40 feet deep and was keyed into bedrock only by sheet pile. Also the drainage ditch leading from the spillway of the dam was placed parallel to the toe of the dam. No internal drainage of the dam was provided. Consequently the ground-water level of the immediate area rose to an excessive elevation into the dam proper. The combinational effects of ground water, weight of the dam and lack of support on the toe of the dam, and the fact that the dam

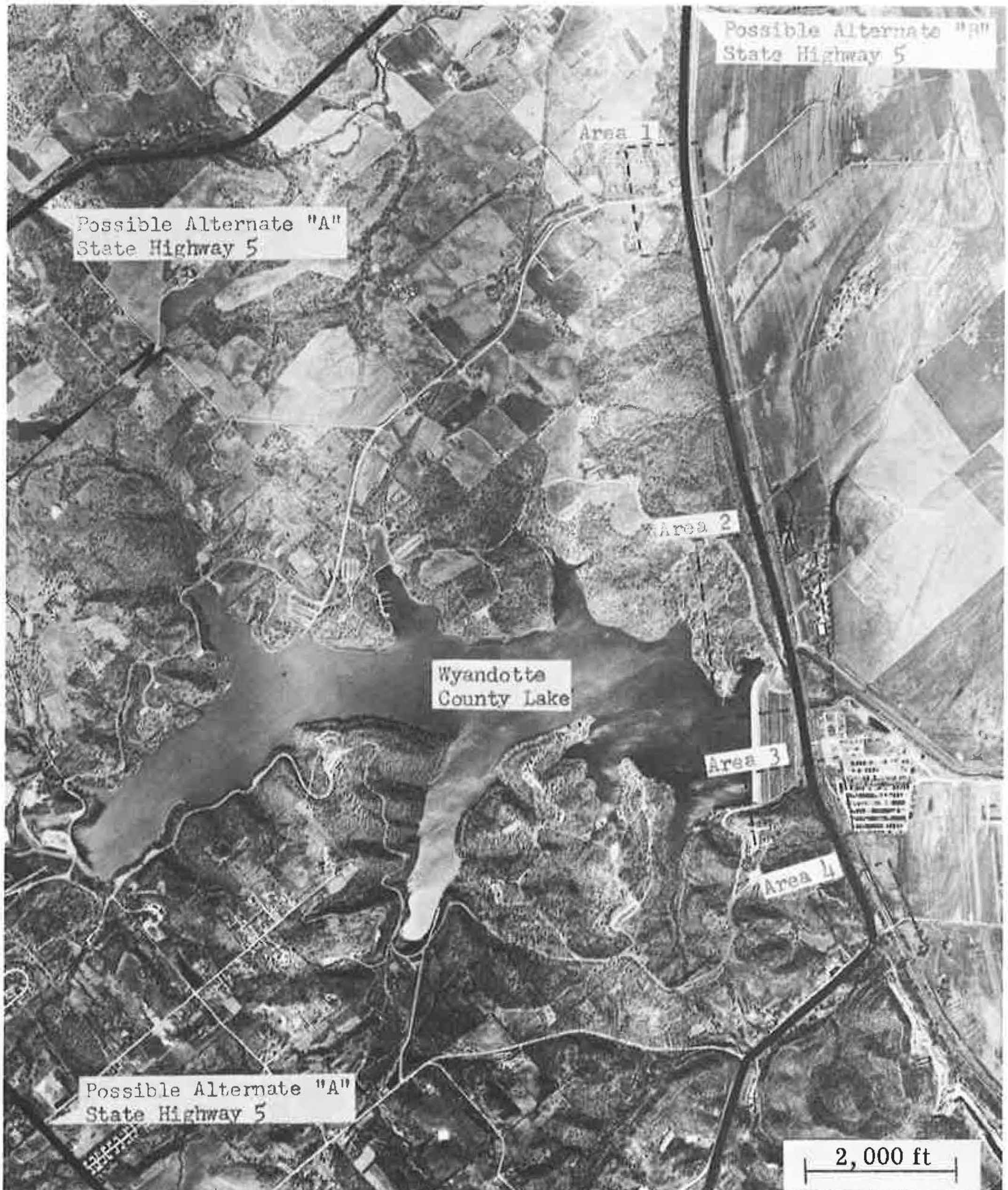


Figure 28. Small-scale aerial photograph illustrating possible Kans. 5 alternate routes and areas of investigation (scale: 1:24,000).

was not well keyed into bedrock, but rather setting on a clay foundation caused the central portion of the dam to fail. The slide plane was approximately 20 feet deep into the clay foundation of the dam.

Subsequently the Corps of Engineers reconstructed the dam. The base of the dam is now keyed into bedrock at varying elevations. The southeast abutment is keyed into the Wea Shale at an elevation of approximately 720 feet. The northwest abutment is keyed into the Block Limestone at an elevation of approximately 707 feet. The base of the dam is 140 feet wide at bedrock.

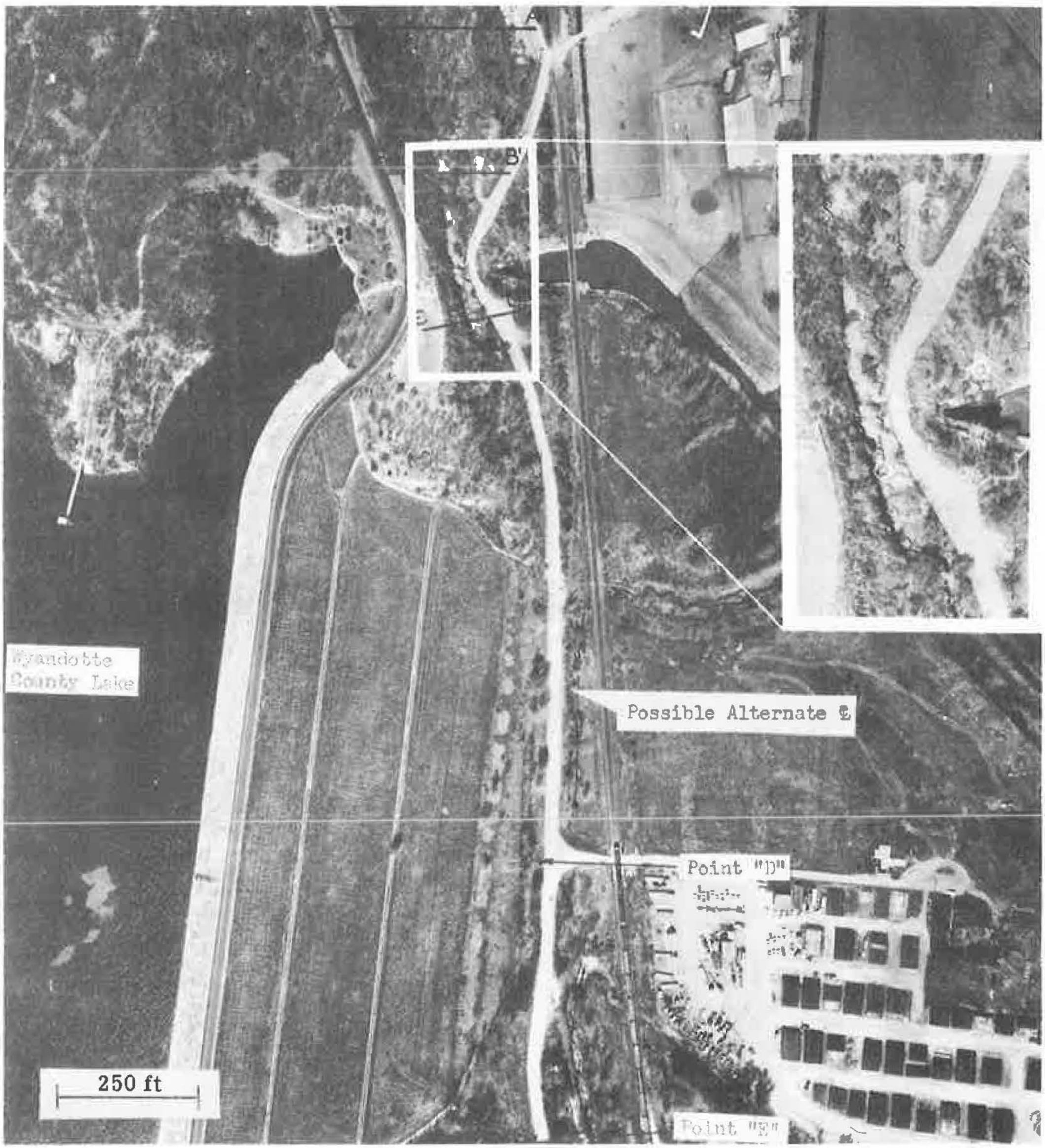


Figure 29. Wyandotte County Lake and possible alternate of Kans. 5 in Wyandotte County; possible alternate route would run approximately along the existing county road; geology targets encircled on inserted enlargement; geologic formations plotted on cross-sections along lines A-A', B-B', C-C' (scale: 1:3,000).

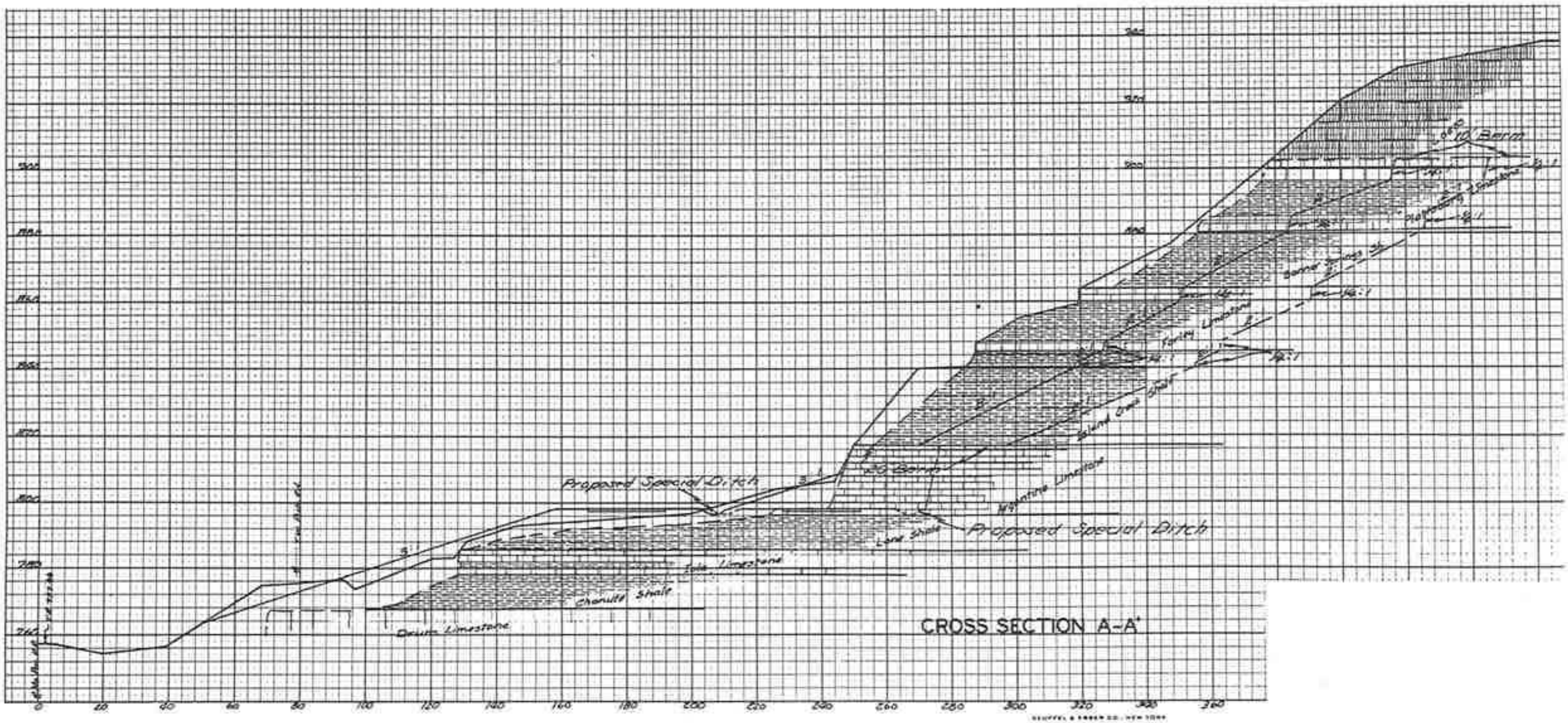

Proposed Special Ditch
20' Berm
10' Berm
Proposed Special Ditch
Lane Shale
Iola Limestone
Chanute Shale
Drum Limestone
Wyandotte Limestone
Island Creek Shale
Farley Limestone
Bonner Springs Sh.
CROSS SECTION A-A'
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

Figure 30.

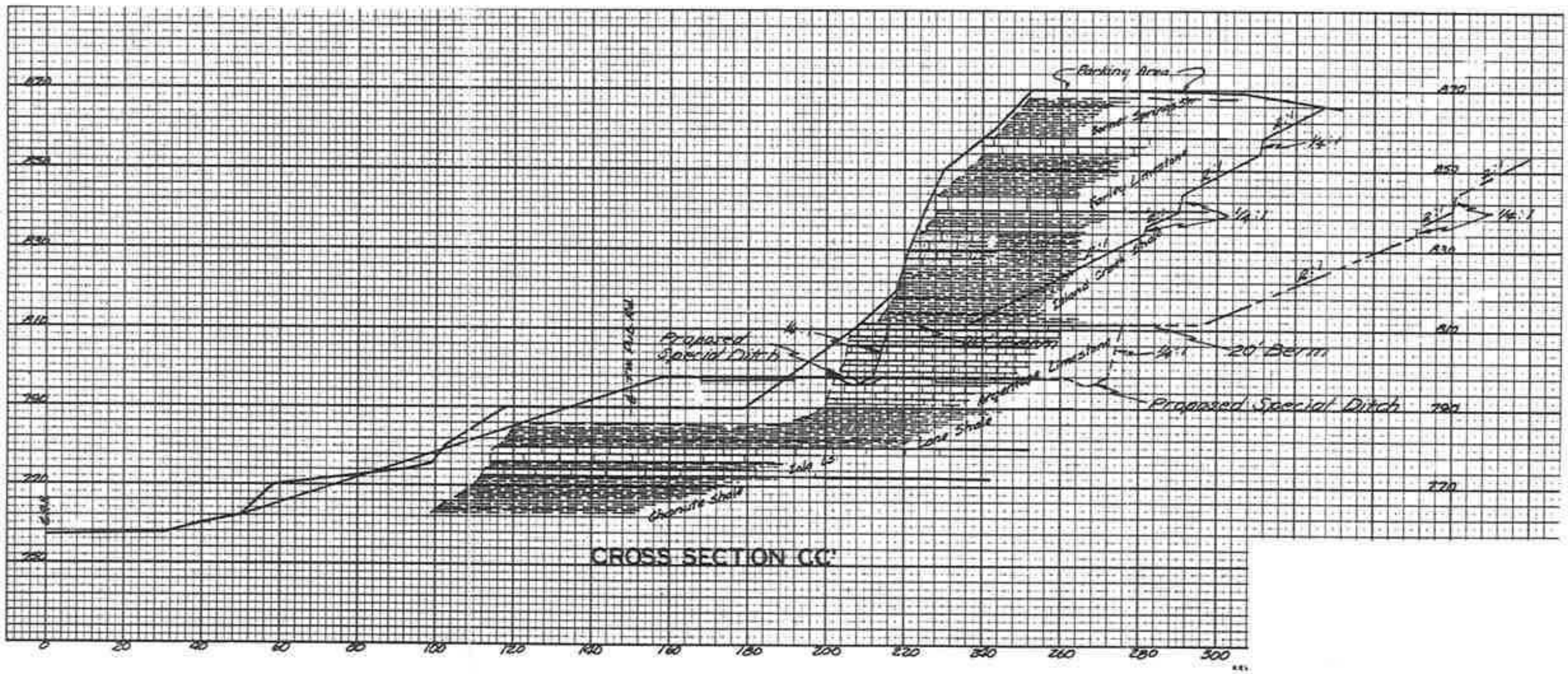
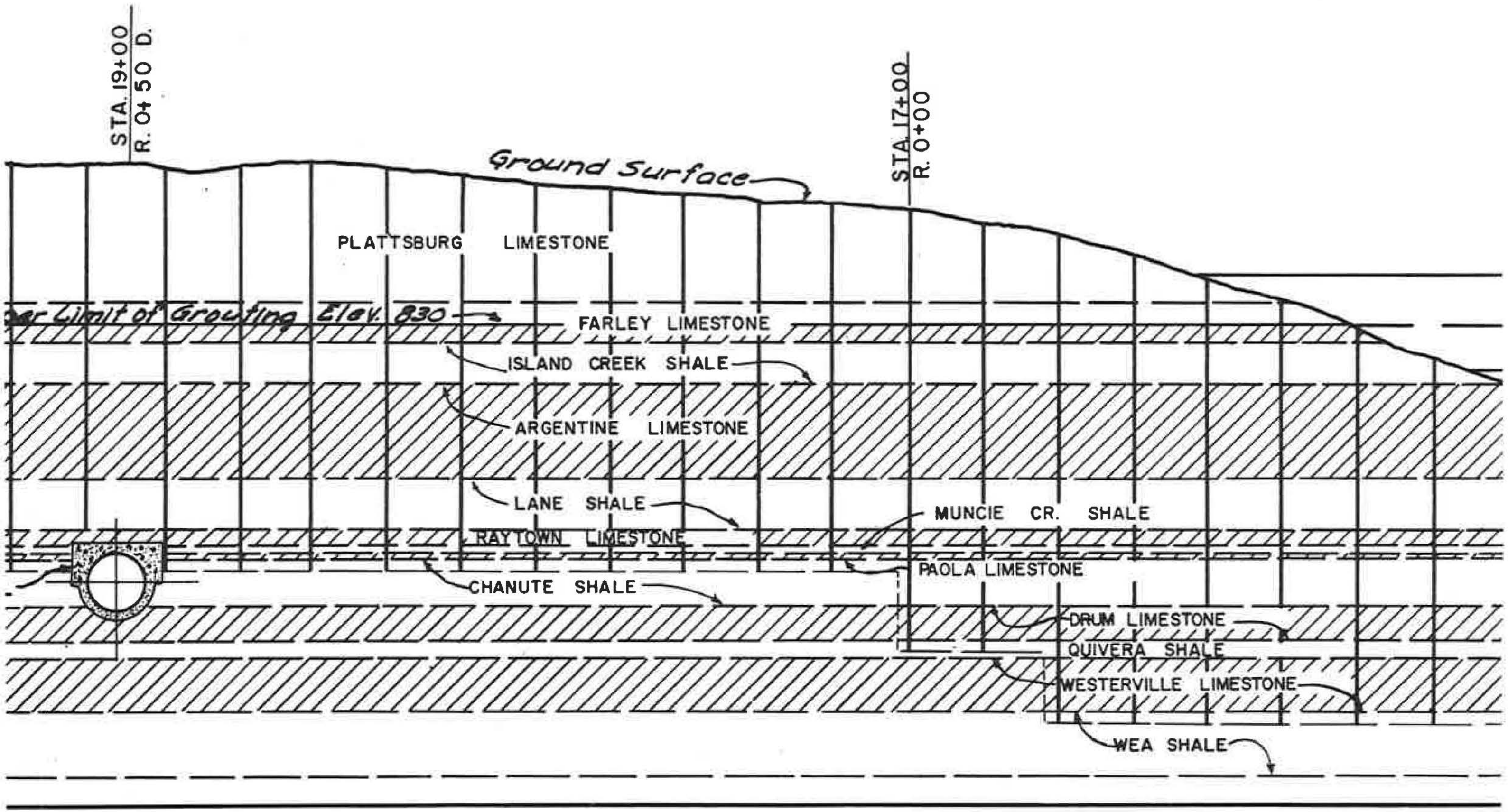

Parking Area
Proposed Special Ditch
20' Berm
Proposed Special Ditch
CROSS SECTION CC'
870
850
830
810
790
770
750
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300

Figure 31.



LEFT ABUTMENT

SECTION ON ℄ OF GROUT HOLES

Figure 32.

Both abutments of the dam were excavated to bedrock. Due to the great amount of limestone present in the area, a great deal of seepage occurred at both abutments. Figure 32 is a portion of a diagrammatic profile of each abutment depicting the location and depth of grout holes which were drilled after the rolled earth fill of the dam was completed. Thirty-two grout holes were placed on the northwest (left) abutment of the dam extending over a horizontal distance of approximately 620 feet. This includes 200 feet of the dam and the area on both sides of the spillway. The southeast (right) abutment was grouted for a horizontal distance of 360 feet including 85 feet of the dam. The lower limit of the grout is at the top of the Wea Shale. [Fig. 32].

Tile drains were constructed in the dam to provide internal drainage of the dam. The drain outlet is located in the center of the dam near the toe. See Point "D". [Fig. 29]

A channel change has provided a spillway drainage ditch leading away from the dam instead of paralleling the toe of the dam.

There is a possibility that blasting of the bedrock in this vicinity will damage the grouting and worsen a now serious problem of seepage through the existing bedrock around the dam. Rock excavation requiring blasting can be anticipated if the proposed centerline is placed near the valley wall in this area.

Hydrology

Groundwater problems will be continuous in areas 2 and 3. They will be numerous in areas 1 and 4 [Fig. 28]. The main avenues of groundwater are at the base of the Argentine Limestone and the base of the Iola Limestone. This situation is made more severe since the general dip of the beds are to the east, thus feeding water away from the lake through the more fractured outcrop area of the rock.

This condition will tend to become more severe in future years as the groundwater solutions out larger cavities in the limestone which will carry larger quantities of water. This in turn will increase the solutioning capabilities of the water.

The source of water for most of the springs in this area is the Wyandotte County Lake; however, springs and seeps were noted in areas 1 and 4 [Fig. 28] which are probably quite independent of the lake source. No groundwater was noted above the Island Creek Shale. The lake's water level is maintained at an elevation of 830 feet which is within the elevation of the Island Creek Shale.

The Drum Limestone carries more water but at a lower elevation and in most cases the water seeps into the valley alluvium. This situation is a potential problem where the fill of the roadbed extends beyond the breakoff edge of this limestone.

Special ditches and underdrains would be needed in all four areas depicted on Figure [28]. Cross Sections AA' and CC' [Fig. 30 and 31] indicate that the present road is setting on the Drum Limestone and Iola Limestone respectively. This is not the case throughout the area as illustrated on cross section BB' [Fig. 32] where the road is setting on fill material. This is a particularly unstable condition since groundwater is running along the contact between the fill material and bedrock. If the proposed roadbed is located above these aquifers, special underdrains will be required to intercept the water. If the proposed roadbed is located below these aquifers, special ditches would be required to handle the runoff. Because of the position of the aquifers, it is possible that a given proposed roadbed level would encounter both conditions present and therefore would require both underdrains and special ditches.

Two separate domestic water supply systems have been built in the area under investigation. Cross section BB' [Fig. 33] depicts one at the base of the Argentine Limestone [See contour map for plan view]. This area is a catch basin approximately 120' × 60' constructed by the landowner. Gravel has been placed on a remnant of the Argentine Limestone (old quarry site), and plastic sheets have been placed over the gravel to prevent surface water from entering the basin. A pipe on the existing county road near cross section BB' is flowing water continuously from this basin. Another pipe depicted on the contour map carries water to the two farm sites located a few hundred feet north of cross sections AA' and BB'. This is the only source of water for these two farms.

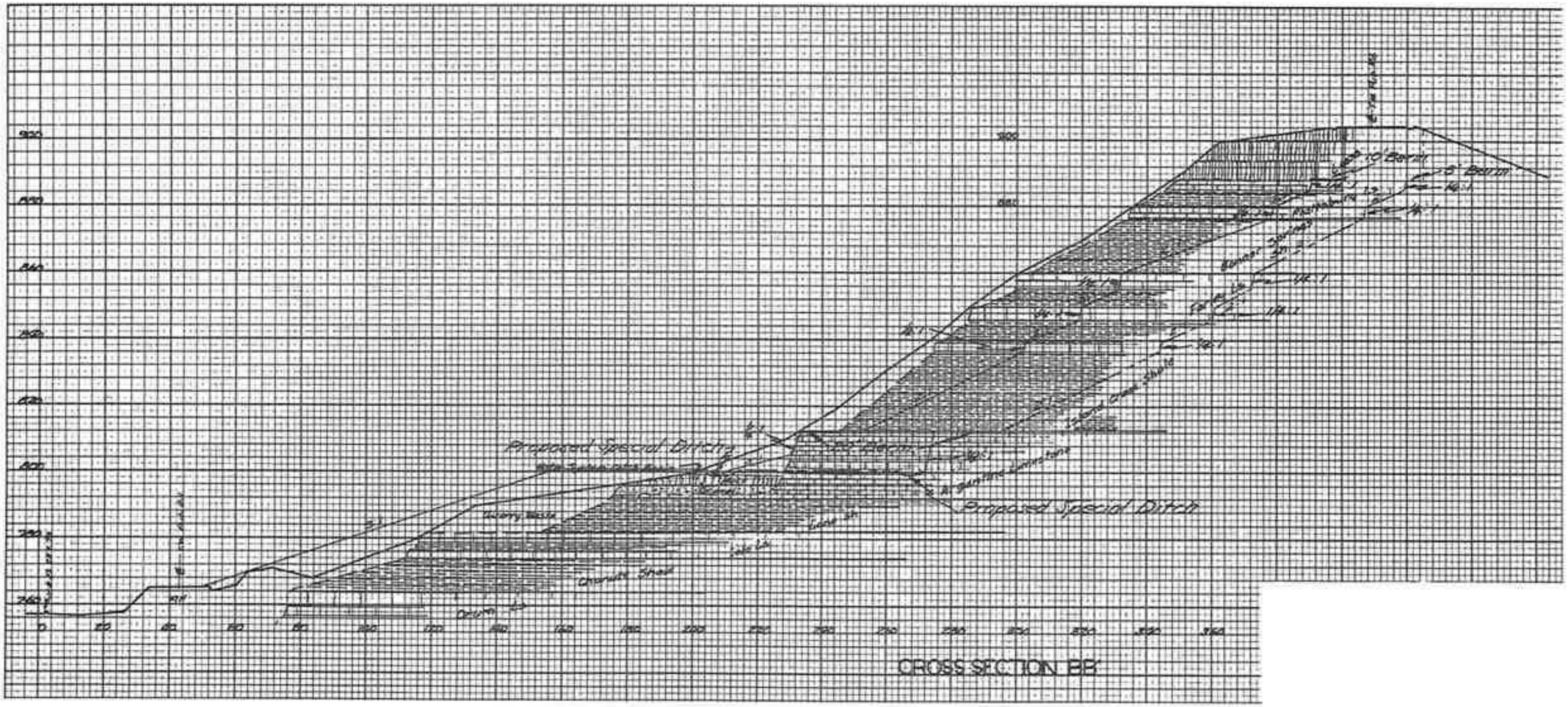

Proposed Special Ditch
Proposed Special Ditch
Chanute Shale
CROSS SECTION BB'

Figure 33.

Another small water system has its source at Point E [Fig. 29] at the present road elevation and the pipe runs northwest paralleling the existing road for approximately 250 feet, then crosses the road to the office of the pipe company located on the north side of the Missouri Pacific tracks. Both systems obtain water from the Argentine Limestone. If the proposed route is followed, these water systems will probably have to be relocated.

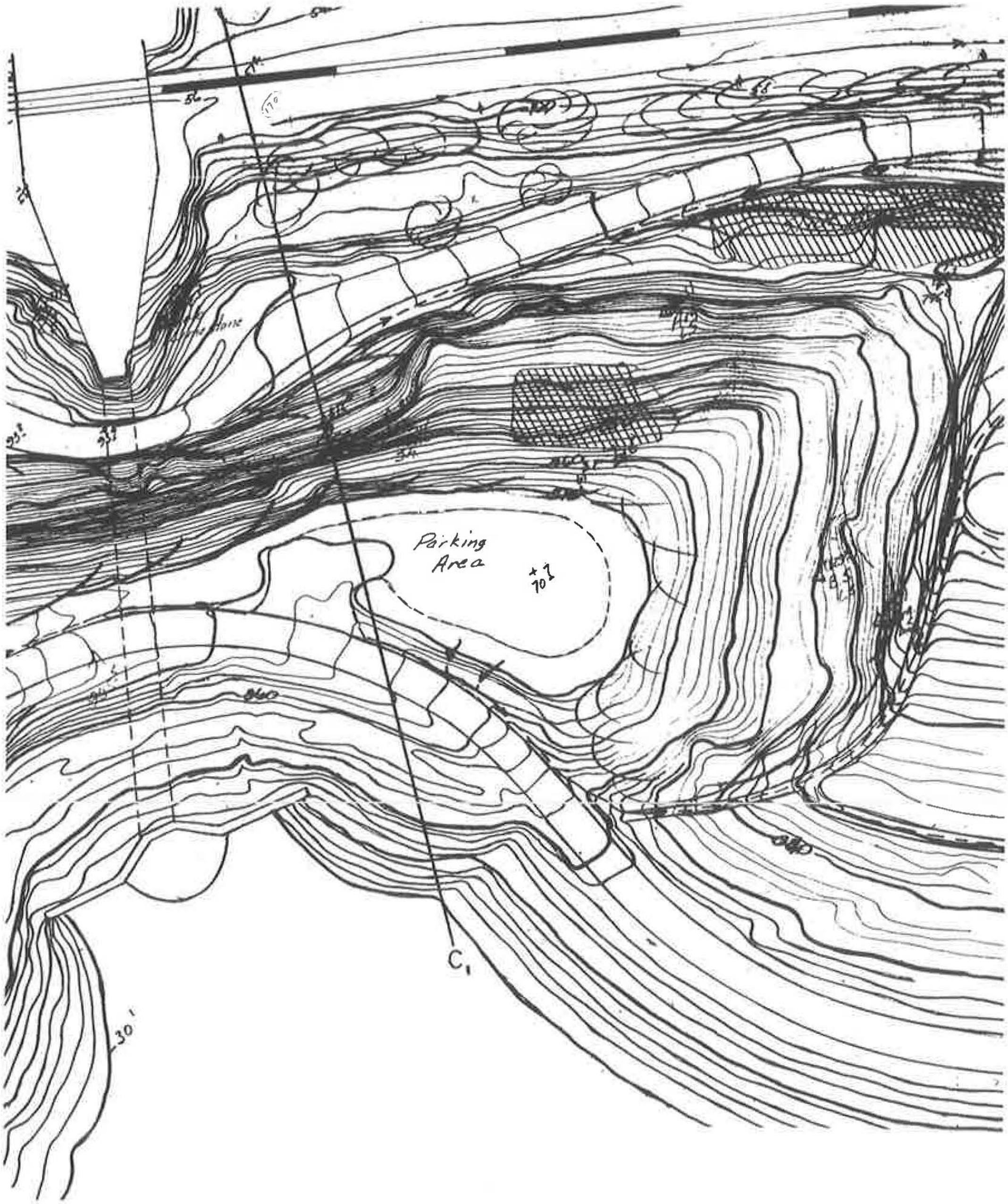


Figure 34.

Rock Excavation

In many areas only a small amount of real estate exists between the railroad right of way and the bluffs of the hill. If the road is placed at a low elevation (present road elevation or lower), rock excavation will be required to provide a sufficient amount of roadway for the proposed project. This is particularly true in the areas depicted. [Fig. 28] In area 2, the Argentine Limestone has been quarried and the existing bench could be used for a roadbed. However, this situation does not exist throughout the area.

Right of Way

If the road is placed at the present road elevation or lower, and rock is excavated, backslopes in the bedrock are suggested as follows: all shale is recommended to be on a 1:1 slope or flatter and the limestones on a 1/4:1 slope. With these recommendations, a 20-foot bench is suggested to be placed on the top of the Argentine-Frisbie Limestone and on top of the Farley Limestone. Thus considerable rock excavation would be required along the face of the existing slope. Also due to the extremely dense tree cover, a great deal of timber grubbing would be required in shaping the backslope.

An acute right of way problem will be encountered at the NW toe of the dam since only approximately 100 feet of real estate separates the dam and the railroad right of way. In area 4 the railroad has constructed their track adjacent to the south boundary of their right of way. Even though the railroad has a right of way 100 feet wide, none of their right of way exists beyond the south limits of the ballast in this area.

Slide Areas

Several slides were noted in this area. Two are depicted on the contour map. [Fig. 34] Mantle creep was noted on all steep slopes in this area. The general steep slopes and the groundwater conditions that exist in this area tend to make any given area a potential slide area. This condition would worsen with grubbing of the vegetation.

Flood Waters

The high water mark in the 1951 flood was approximately 575 feet which is over the existing road in areas 2 and 3.

SUMMARY

Regardless of the elevation of the proposed centerline in this area most of the problems and situations mentioned in this report cannot be avoided. From the geo-engineering point of view this area can be described as a rather difficult area for highway construction. If this area is selected for the proposed roadway, right of way will probably be required out at least as far as the top of the bluff, special ditches and underdrains will be necessary; at least two sources for domestic water systems will have to be relocated; extreme caution would be required during blasting operations to prevent the possibility of damage to the grout which was forced into the rock voids around the dam area; right of way would be scarce in areas where the Missouri Pacific Railroad right of way is near the valley wall and the toe of the existing dam; the backslopes would have to be very carefully constructed to prevent spall and slipouts; and unless all groundwater is intercepted and the anticipated increase of groundwater flow in future years is reckoned with, the maintenance of the finished roadway may prove to be a continuous and very expensive operation.

Appendix B

Abridged Edition

Preliminary Photo Geological Report, Brown County, Morrill to Sabetha Centerline Selection.

General Information

Two lines are being evaluated for the route location, Line A (north line) which is 5 miles long and Line B (south line) which is 6 1/4 miles long.

Both lines are located in similar topography. On Line A the relief varies from 1,116 feet in elevation to 1,285 feet in elevation, a difference of 169 feet. On Line B the relief varies from 1,140.5 feet in elevation to 1,322.5 feet in elevation, a difference of 182.0 feet.

Since no grade is available, only an estimate on the number of cuts is presented. It is estimated that Line A will have five major cuts of more than 10 feet in depth and five minor cuts less than 10 feet in depth. It is estimated that Line B will have one major cut and seven minor cuts. A more detailed analysis of the geo-engineering aspects is presented subsequently.

Regional Geology of the Area

The geological section that will be encountered on these projects will range from the Crouse Limestone Member, Council Grove Group, to the Cottonwood Limestone Member, Council Grove Group. Glacial till of Pleistocene Age caps most of the hills encountered on centerline, especially on Line B. The section thickness was obtained from field notes of Project 75-7 F 152-A which joins both centerlines of this project.

The general structure along centerline is a gentle west dip with a slight reversal of dip along the central portion of the project on Line A. Due to insufficient exposures of bedrock along Line B, a true representation of the structural geology cannot be presented.

Along Line A most of the high areas on the western half of the alignment are stabilized by bedrock. Usually the eastern slope of these hills consist of thick glacial till. Along Line B, all of the alignment consists of glacial till with the exception of approximately 2 miles of the central portion of the project where bedrock is exposed in lower areas.

Geo-Engineering Aspects

All cuts are referenced to centerline stationing. The characteristics of each geologic formation that would be encountered in each cut is described to help ascertain the excavation classification. Also all seep areas are located and their source determined to help evaluate general groundwater problems. [A detailed listing of these factors was given in the full report.]

Summary

A comparison of the two lines can only be presented in terms of estimates and potentials since the vertical location of the centerline grade will affect the amount of rock quantities and over-all grading quantities.

Ground relief is more erratic on Line A and consequently more major cuts of greater than 10 feet will be encountered. These cuts on the western half of this alignment will encounter rock excavation. These rock formations are encountered on construction Project 75-7 F 152-A which joins the west end of this project. From the experience encountered on this construction project, underdrains may be required in the same formations on the Morrill to Sabetha Line A alignment.

Even though Line B is the longer of the two lines, the relief is less erratic. Cuts will be less numerous and no rock excavation will be encountered except for the two small cuts previously mentioned.

Seep areas that are noted are present in glacial till on both lines.

Appendix C

Abridged Edition

Stream Migration Study of Turkey Creek, Wyandotte County, Kansas

Introduction

The purpose of this report is to present information obtained from a stream migration study of Turkey Creek in Wyandotte County, Kansas.

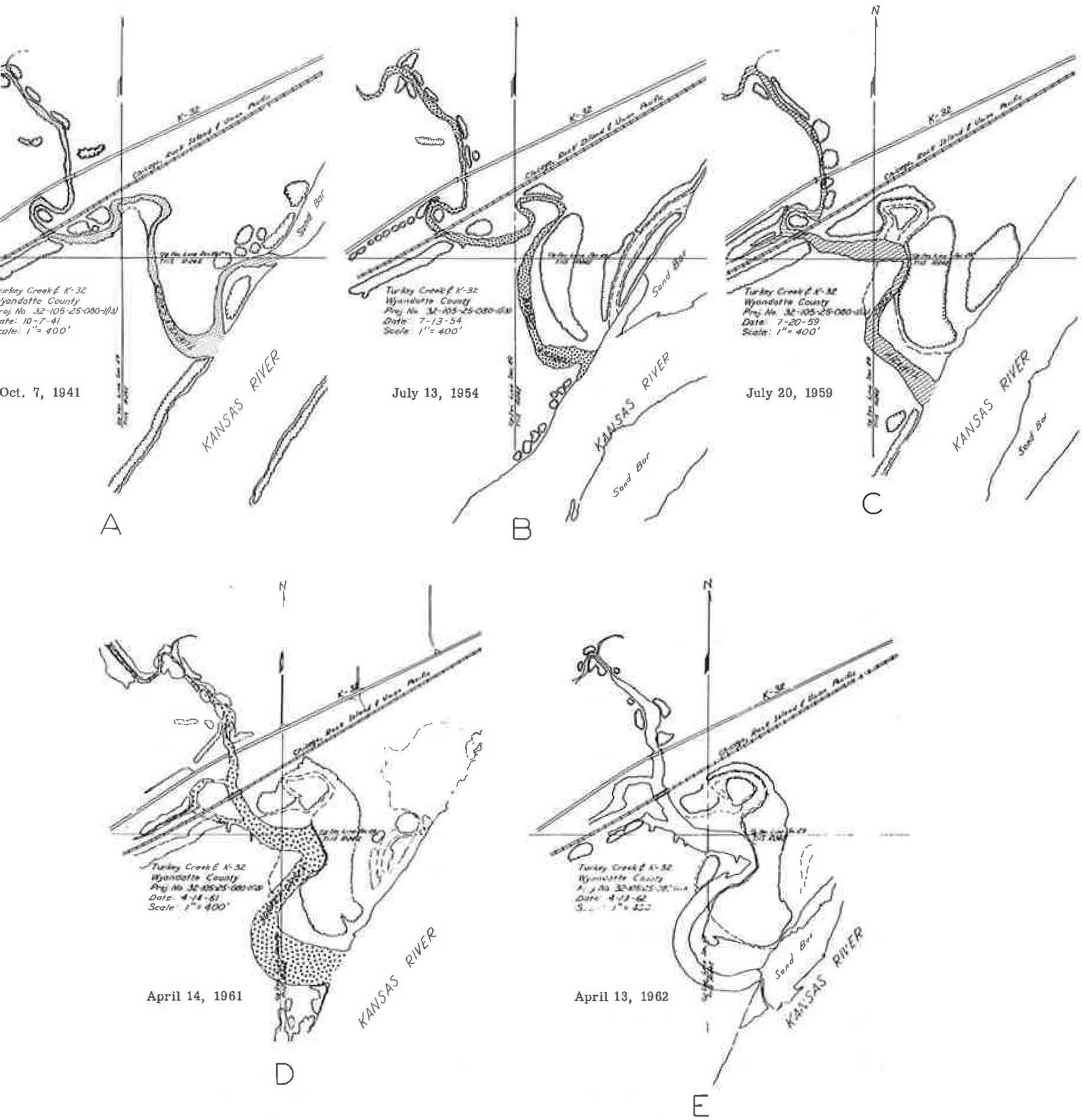


Figure 35. Stream migration patterns of Turkey Creek in Wyandotte County, Kans.

An opinion is herein presented as to the cause of the migration and the subsequent damage that is being incurred on the adjacent farmland.

A pictorial presentation of the stream's activity for the past 22 years is presented in graphic form in this report to supplement and to illustrate the author's opinion on the stream's development.

Five sets of comparable stereo photographs were studied. Stream configurations for each of the years are depicted on Figure [35]. The original illustrations were drawn to a scale 400 feet to 1 inch.

Field elevations taken during the month of August 1962, and elevations taken from the 1925 plans were used in this analysis. Stream profiles for each year studied are presented to illustrate and to supplement the author's analysis. The following photography was studied:

Photography	Scale of Photography	Date of Photography
AAA	1000 feet to 1 inch	7 Oct. 1941
AAA	1000 feet to 1 inch	13 July 1954
AAA	1000 feet to 1 inch	20 July 1959
SHC	400 feet to 1 inch	14 Sept. 1961
SHC	200 feet to 1 inch	13 April 1962

Procedure

By using elevations of a known date and data obtained through photographic interpretation procedures, the time and the extent of stream degradation and a prediction of future stream activities is presented in this report. By using photography of the area which was flown on the dates listed previously, the width of the stream at selected points and the extent of bank sloughing was studied. There appeared to be a close relationship between the width of stream, the sloughing and the degradation of the stream's bottom. Since the stream's banks can be measured for each of the years studied and the extent of sloughing can be observed for each of the periods, the stream degradation could be dated, located and correlated.

Table 1

Year	Extent of Detectable Sloughing
1941	Sloughing extends from mouth of stream to a point approximately 250 feet south of railroad bridge.
1954	No difference noted from 1941.
1959	Sloughing extends 160 feet north of railroad bridge.
1961	Sloughing extends 175 feet north of highway bridge.
1962	Sloughing extends 1,200 feet north of highway bridge.

Table 2
Width of Stream by Year

Year	Point A (420 feet north of stream's mouth)	Point B (250 feet south of railroad bridge)	Point C (200 feet north of highway bridge)
1941	120 feet	70 feet	30 feet
1954	200 feet (meander migration)	70 feet	30 feet
1959	145 feet	150 feet	30 feet
1961	60 feet (stream was at flood stage and width was estimated)	65 feet	50 feet
1962	60 feet	65 feet	60 feet

The main portion of the stream migration study pertains to the measurement and plotting of various meanders and reaches in the area under investigation. By studying the dated aerial photography of the same area, the amount of active lateral bank erosion and stream bed shift could be ascertained for the period of years between successive photographic coverage. The magnitude and the location of active stream degradation was ascertained by this procedure and consequently traced from one photographic year to the next. Known data on two man-made features [Turkey Creek channel changes dated 1954 and 1961] which affected the stream's flow, allowed the correlation of the degradation activity and these man-made features.

By using some known stream elevations taken in the year of 1925 (bridge plans) and stream bed elevations taken in 1962, the stream bed profiles were estimated for each photographic year based upon stream banks sloughing and migration evidence obtained from the stereoscopic study of the aerial photographs.

Conclusions

In essence, the erratic nature of Turkey Creek in the area of Highway K-32 bridge in Wyandotte County can be for the most part contributed to the two channel changes. Degradation of the stream bed at the bridge site has been of greater magnitude during the past four or five months and consequently the abutments of the old bridge are in immediate danger. Once the old bridge abutments are removed by erosive action only a short period of high velocity water could undermine the earth embankments on which the present bridge is sitting. Preventive maintenance of placing rock rip rap around and under the bridge has been implemented at the time this report was written.

Similar action would have probably occurred in years to come; however, the abrupt change in stream gradient accelerated the erosive action.

Stream degradation will continue in Turkey Creek especially upstream. Active sloughing of fields has been detected to the north of the highway bridge and will continue to do so in months to follow.

To date most of the degradation of the stream channel has been in a fine sandy loam or a very easily eroded material. This fact helps to explain the high rate of erosive action during the past three years. Approximately 200 feet upstream from the highway bridge, the stream is now cutting a much tighter more cohesive clay to silty clay. Consequently the rate of degradation will become slower upstream and will extend over a longer period of time.

Bedrock is approximately 10 feet below the stream bed at the bridge site, therefore a great deal of degradation will take place before an even more resistive material will be encountered.

From studying the present stream profile, a prediction that continued degradation in and around the highway bridge can be made. This will probably be due to stream adjustment downstream (stream channel is 5 feet higher at the bridge than at the river) and not necessarily a direct compensation of the abrupt change resulting from the two channel changes. It is believed that the majority of the degradation resulting from the two channel changes has already occurred at the bridge and is now more active upstream.

On future projects when channel changes are contemplated, it is suggested that an investigation be undertaken to ascertain soil conditions, gradient change and possible results of the change in terms of damage to real estate, highway structures and other property.

Appendix D

Abridged Edition

Stream Degradation Study of Wolf Creek and Proposed Channel Change, Wyandotte County, Kansas

Introduction

This report presents information pertaining to a stream degradation study of Wolf Creek and a proposed channel change near Bonner Springs, Kansas. The channel change is a portion of the proposed K-32 highway improvement in this area.

The information presented herein was obtained through photographic interpretation and field investigations. Photographs dated July 1941 and March 1962 with scales of 1:12000 and 1:3,000 respectively were used in this study.

General Information

The location of the proposed channel change is on a meander of Wolf Creek on the southwest edge of Bonner Springs, Kansas. The K-32 alignment crosses Wolf Creek at two points. The purpose of the channel change is to avoid the construction of two structures over this stream and to provide fill material for the proposed roadbed.

Figure [23] illustrates the location of the proposed channel change in relation to the proposed K-32 centerline.

The Wolf Creek valley is approximately 1500 feet wide at this point. The valley plain is made up of alluvial silts and clays (plastic index 20 to 42) with glacial clays capping the valley walls to the north and south. The valley is approximately 45 feet deep. Bedrock is exposed on both sides of the valley. The location of the bedrock "break off" on the south side of the valley may be an important factor in the final location of the proposed channel change.

Four bridges cross Wolf Creek in this immediate area. The Union Pacific Railroad crosses Wolf Creek near the mouth of the stream. Two county roads [Points A and B, Fig. 14] cross the creek several hundred feet upstream from the mouth of the stream. The present K-32 highway crosses Wolf Creek more than a mile above the stream's mouth.

Farmland is located on both sides of the present stream's channel in this valley.

At least two terraces are present, the lower one being the best farmland. The lower terrace is also more silty than the upper terrace and consequently is more vulnerable to erosive action.

Present Stream Condition

During the past 22 years Wolf Creek has been a stable stream; that is, no major migration tendencies were detected. The channel is essentially as it was in 1941. Currently, some degradation is taking place in the channel. Active sloughing or lateral bank erosion has been detected in many places along the stream's banks. Figure [14] depicts some of the areas of active sloughing. The stream bed profile depicted several sharp breaks which coincide with the areas of active degradation or where bedrock is being encountered in the stream bed.

Bridge Structures

As mentioned above, four bridges are present in the immediate area of the channel change. The Union Pacific Railroad bridge is located near the Kansas River, the elevation of which controls the base level of Wolf Creek. Recently rip rap has been placed around the bridge. The structure is such that much debris has and will collect at this point. The stream is degrading several hundred feet upstream at a point that active sloughing is taking place.

The county bridge located at Point "A" is relatively new and appears to be in good condition. It will be approximately 700 feet downstream from the end of the proposed channel change. Both abutments are setting on alluvial deposits. No active degradation or sloughing was detected near this structure.

The county bridge located at Point "B" is an older structure. The south abutment has been rebuilt of concrete and the north abutment is stone and is believed to be the original abutment. The bridge is setting on approximately 13 feet of alluvial silty clay with a plastic index of 14 to 20. One hundred feet downstream is a major break in the stream's profile [Point C, Fig. 23]. This is caused by loose rock that has been placed there probably during the reconstruction of the south abutment of the bridge. Active bank sloughing is present downstream from this point. Also active bank sloughing was detected approximately 400 feet upstream.

The K-32 bridge is located well over a mile upstream from the channel change site. The stream's channel encounters bedrock in two locations between the channel change site and this bridge and should any degradation take place as a result of the channel change, the bedrock will contain this activity.

Stream Degradation Study

The area of main concern in this study is the meander of Wolf Creek south of Bonner Springs near which the intersection of K-32 and the Loring spur will take place and the channel change is proposed. Figure [23] depicts the general relationship of the above. The proposed channel change would cut off the upper portion of this meander and would eliminate two bridge structures on the same; however, some form of drainage would have to be provided for approximately 50 acres drained by the gully depicted at Point "D" on Figure [23].

The fact that a slaughterhouse located at Point "E" [Fig. 23] empties sewage in the present Wolf Creek channel will present a sanitation problem since this point will be bypassed after the channel change is operational. If the channel change is completed, this problem will demand special consideration since the Highway Commission may be held liable for the resulting sanitation problem.

The channel change itself will cause detrimental effects on surrounding farmland and bridge structures. It is impossible to place a definite time element to this action but by observing the present condition of the stream channel and comparing it to the condition of the stream bed as a result of the channel change, it can be ascertained that some damage will be incurred. This is especially true where active lateral bank erosion is now taking place.

It is believed that such action will be at a slower rate than that of Turkey Creek [Wyandotte County, Memorandum dated September 1962] because of the more cohesive material and the presence of bedrock.

A major break in the original profile is present at Point "C" [Fig. 23]. This break is immediately downstream from the county bridge depicted as Point "B" on the enclosed illustration and immediately above the start of the proposed channel change. The break is caused by rock and rubble that has been placed in the stream at that point and is not a permanent condition. This was ascertained by limited drilling in this vicinity. Once the rock and rubble is removed by higher velocity water currents, the bridge in question would be in jeopardy. The channel change will shorten the channel by approximately 1,300 feet and consequently steepen the stream gradient immediately below the break in the stream bed profile at Point "C". The stream's meander is approximately 2,300 feet long with a 6-foot difference in elevation within this distance. The channel change will be approximately 950 feet long with the same 6-foot difference in stream elevation within its length. Unless there is some type of "check" in the resulting erosive action, the stream will degrade to a lower level (approximately 5 feet) at the site of this bridge which would, no doubt, cause the collapse of the structure. Sloughing of stream banks would result as far as 1,300 feet upstream where bedrock is encountered. The bedrock will tend to stabilize this condition. However, due to the increase in stream current velocity as a result of the channel change, there is a high probability that lateral bank erosion will take place above this point especially in areas where bank sloughing is now active.

Some scouring action may take place downstream as a result of the increase in velocity of the stream's current, but due to the proximity of the stream's mouth, this erosive action will not be of the same magnitude as similar action upstream.

From the information obtained from the soil survey, it can be surmised that the channel change as surveyed in the field is located near the break off of the bedrock. No detailed geological investigation has been accomplished.

The upper 15 feet of the material is a tight cohesive clay (glacial till) and the lower 15 feet is a less cohesive silty clay. This condition is conducive to the undercutting of the overlying clays. This condition exists in some areas along the present channel which helps to explain some of the present bank sloughing. Also with the presence of bedrock to the south, the stream degradation will be forced to the north in the silty clays which is a less resistive material than the bedrock. This will be especially true if the channel change is located at any one point on the break off of the bedrock. An approximate bedrock "break off" is depicted on Figure [23]. This line is generalized since no definite information could be obtained at this time. The break off will be further north at greater depths.

It is anticipated that bedrock will be encountered on the east end of the channel change and will be in alluvial deposits on the western end of the channel.

It is suggested that if the channel change is made, a detailed geological investigation be made to determine the exact break off of bedrock at the elevation at which the bottom of the channel change will be placed. Also it is believed that the channel change should be placed on bedrock for the entire length of the channel to stabilize the resulting scouring action and to prevent the stream action from cutting a new channel to the north if bedrock is encountered on only a portion of the proposed channel. This would entail moving the channel to the south on the western end of the proposed centerline as depicted on Figure [23] as an alternate line. This line may have to be curved to the south to encounter sufficient bedrock for this purpose. This should be done only if bedrock is present along the entire proposed centerline on the channel. Otherwise the resulting straighter stream channel will have a faster current veolcity and will have a greater scouring potential than the original proposal.

Appendix E

Abridged Edition

Condition Survey of the Kellogg Bridge Deck, Wichita, Kansas, by Photographic Interpretation Procedures

Introduction

The purpose of this report is to present the procedures and problems that were encountered during the process of delineating first and second generation patches on the Kellogg Street bridge deck in Wichita, Kansas. This study was accomplished for the Research Department of the State Highway Commission of Kansas in order to obtain a permanent record of the bridge deck condition at the time of the most recent photography.

Three sets of photography were utilized for interpretation purposes; two that were taken by the K-22 camera with scales of 38 feet and 56 feet to one inch and one set taken by the Wild RC-8 with a scale of 90 feet to one inch. Henceforth, this photography will be referred to as follows:

Set A	K-22	Scale 56 feet to 1 inch
Set B	K-22	Scale 38 feet to 1 inch
Set C	RC-8	Scale 90 feet to 1 inch

Date of Photography - August 1961.

Procedure

Initially, the mapping of the bridge deck took place on photographic enlargements (scale approximately 25 feet to one inch). A great deal of difficulty was encountered during this process and the anticipated accuracy of the finished product was below expectations.

In order to utilize Set C photography and be able to map at a large scale, it was decided to utilize the Kelsh plotter. Field control was run and additional control was obtained from the plans of the bridge. If the deck is to be mapped in the future, all control is filed in the photographic interpretation files.

Five stereoscopic models were required to obtain full coverage of the bridge deck.

The bridge deck was mapped at a scale of 20 feet to one inch. Different colors were used to depict the different generations of patches and the original bridge deck. Approximately nine days were required to complete the project with the Kelsh plotter.

Procuring Desired Photography

The initial problem was to obtain large scale photography. A scale of 25 feet to one inch was believed to be large enough for road condition surveys. The maximum scale that can be obtained with the State Highway Commission's Wild RC-8 (6" focal length) camera is 100 feet to one inch and still obtain good quality photography and be above the minimum legal flight height. In order to obtain the desired scale photography, the Photogrammetry Section borrowed a K-22 Air Force Camera and a 24-inch focal length cone from the Kansas Air National Guard. Using this focal length, the aircraft would have to fly a flight height of 600 feet which is above the minimum legal height to obtain photography at the scale of 25 feet to one inch. Through trial and error procedures, it was discovered that good quality photography can not be obtained at such low altitude because of image movement and limitations due to hyperfocal distance specifications of the 24-inch focal length cone. By conforming to the specifications of the cone, it was discovered that the minimum flight height for obtaining good quality photography was 1800 feet. At this height a 24-inch focal length camera would take photography at a scale of 75 feet to one inch compared to 100 feet to one inch that can be obtained by using the Wild RC-8 Camera. Since the K-22 photography is inferior to the RC-8 photography and only a minor difference exists in the scales, the latter was selected for interpretation purposes.

For a detailed account of the testing results of the cameras, the author makes reference to Photogrammetry Section's "Memorandum to the Files" dated 23 August 1961.

It is believed more tonal contrast can be observed with photography taken at noon or when the sun's rays are nearly normal to the bridge deck. Set B is the only group of photographs that were taken at approximately 12:00 noon. Set A was taken at approximately 10:30 a. m. and Set C was taken earlier in the morning.

Photography Sets A and B are blurred because of image motion and improper focusing of the lens. However, much information was derived from both sets of photography because of the larger scales and the better lighting conditions at the time the photography was taken.

Set C photographs are sharp and have good contrast but have smaller scale and poorer lighting conditions. This scale was too small to make a direct tracing of the patch system since the smaller patches were too small to be a mappable unit.

Photography Sets A and B were printed on glossy, single weight, paper while Set C was printed on semi-matte, single weight, paper. The glossy print is believed to be better for interpretation purposes. All three sets were used during the mapping process.

Photographic Interpretation

Initially it was thought the interpretation aspects would be a relatively simple operation if the photographs would depict the patch boundaries. Actually if the patches were clearly defined no interpretation would be necessary. The process would involve only the tracing of the patch boundaries from the photographs to the base map. Most of the patch boundaries are distinguishable but erroneous results can be obtained because of two reasons. (1) The first and some of the second generation patches have acquired a tone similar to that of the bridge deck through wear and "road scum". (2) The "road scum" acts as a blanket, thus covering up the patches' boundaries and form "pseudo" boundaries which depict the limits of the blanket. This is especially evident in the outboard lanes.

Three clues were utilized to detect and differentiate the "road scum" effects from the true patch boundaries. (1) The "pseudo" boundaries appeared more erratic and lacked the methodical pattern that the patch work system depicted. (2) The "pseudo" boundaries would often cross or extend through distinguishable patch boundaries. (3) The "road scum", while having a definite boundary at one point, would blend into the adjacent tone of the patches or bridge deck elsewhere.

Anticipated Accuracy

Accuracy of the completed product is contingent upon three factors. (1) The accuracy with which the Kelsh plotter was set up. (2) The placing of the floating dot on the Kelsh plotter by the plotter interpreter. (3) The selection of the patch boundary by the photographic interpreter.

Because of the amount of control that was available for the Kelsh plotter "set up", the inaccuracies resulting from the first factor would be nominal. It is believed inaccuracies resulting from the second factor would be insignificant as far as the overall accuracy of the map is concerned. The majority of the percentage of error present in the completed product can be attributed to the third factor. This is only true where the patch boundaries are not well defined on the aerial photographs. In essence, the inaccuracies of the completed map exist in areas where the patch boundaries are not clearly defined on the aerial photographs.

The author can not place a percentage reliability factor on the map since no true comparison of the actual bridge deck can be made. A verbal description of the accuracy of the finished product is presented giving approximate percentage values of the different sections of the bridge using the sections where the patches are clearly defined as a basis for comparison. Information from field notes was also used in the evaluation of the map's accuracy.

Outboard Eastbound Lane -	Two generations of patches. 1st Generation From the west abutment to Station 132 + 80, fair accuracy, at least 70% of the patches are accurately placed. Not all patches were detected. From Station 132+80 to Station 137+30, poor to fair accuracy, probably not more than 50% of patches accurately placed. Extreme difficulties in interpretation. From Station 137+30 to Station 140+15, same accuracy as first section. From Station 140+15 to east abutment, patch boundaries are accurately placed. 2nd Generation All patches are accurately placed.
Inboard Eastbound Lane -	One generation of patches. All patches are accurately placed.
Inboard Westbound Lane -	One generation of patches. All patches are accurately placed.
Outboard Westbound Lane -	One generation of patches. West abutment to Station 140+50, fair accuracy, at least 70% of patches are accurately placed. From Station 140+50 to east abutment, all patch boundaries are accurately placed.

Recommendations

If similar projects are to be undertaken in the future, the following recommendations are suggested:

1. Photography should be taken near noon time using the State Highway Commission's Wild RC-8 camera.
2. The Kelsh plotter should be utilized to map the patch boundaries.
3. Color photography should be utilized for interpretation purposes, if the project is as complex as the Kellogg Boulevard bridge deck.
4. All work should be continuous on such projects. This project was spread over a year's time. The full benefit of the field work was partially lost and each renewal of the project necessitated a review of work already accomplished.

Vertical and Horizontal Bridging with the Kelsh Stereoscopic Plotter

JOE V. EVANS and PETER MALPHURS, Respectively, Photogrammetric Engineer and Photogrammetrist, State Highway Department of Georgia

• SECOND ORDER stereoscopic plotting instruments are capable of obtaining a theoretically correct solution of double point resection under certain conditions. Hypothetically, it is possible to adapt the "base-in, base-out" method of first order optical train aerial triangulation instruments to a Kelsh double projection, stereoscopic plotter and achieve results for limited photogrammetric operations (1).

This technique for transferring the external orientation of a controlled stereoscopic model to uncontrolled stereoscopic models is based on the principle of spatial resection. Each succeeding photograph printed as a transparency on optically flat glass and called a diapositive in this paper is oriented to the preceding one, which contains a correct internal and external solution. By carrying the orientation forward in this manner, a series of highly predictable errors are incurred which can be adjusted to yield accurate information.

The equipment used in this test was a standard two projector Kelsh photogrammetric instrument and a desk calculator. The highway department's electronic computer was not used in any of the calculations, although the adjustment of errors could be accomplished by strictly analytical means with the aid of a computer.

No claims are made for originality of the basic principles involved, but a presentation of the procedures developed and a summary of the results obtained may be of interest to those involved in compilation of maps by photogrammetric methods.

PREPARING THE DIAPOSITIVE

Each diapositive plate is marked with 9 evenly spaced crosses near its perimeter and center (Fig. 1). This can be accomplished by making fine cuts in the emulsion by use of a razor blade along a straightedge. These marks are not critical as to exact location with the exception of the center cross referred to hereafter as the radial center, which should be accurately positioned at the intersection of undrawn line extensions between each pair of fiducial marks. The crosses near the perimeter should be about 2 in. from the edge of the photographic plate to prevent them from being projected off of the table top.

DOUBLE PROJECTION INSTRUMENT OPERATION

The first and last stereoscopic model of the aerial photography strip to be bridged should be fully controlled. The control points required are the same as in accepted practice for bridging by use of first order, optical train, instruments, two horizontal three vertical control points on every fifth stereoscopic model, andfull control for every sixteenth stereoscopic model of no less than three horizontal and five vertical control points. A base sheet, long enough to encompass a five-model section, is prepared on a scale stable base drafting film and all horizontal control points are accurately plotted thereon to the scale at which the stereoscopic models will be given absolute orientation.

Paper sponsored by Committee on Photogrammetry and Aerial Surveys.

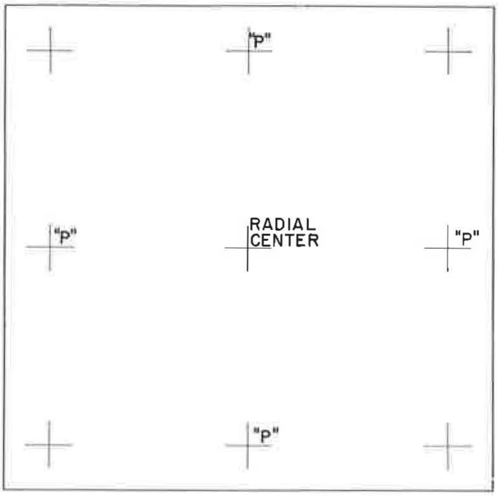


Figure 1. Marked diapositive plate.

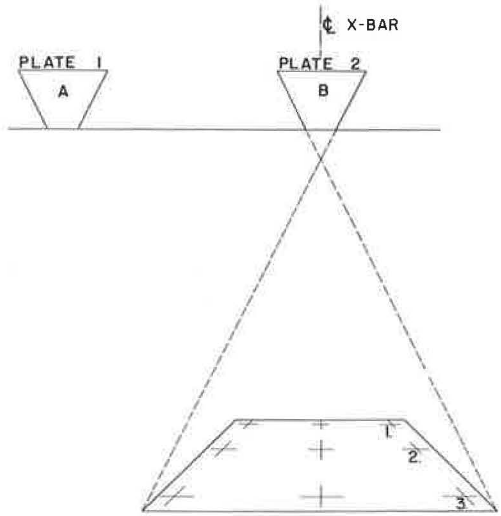


Figure 2. Starting position of projectors.

1. The first step in this process is recording the exterior orientation which is accomplished as follows:
   a. The initial stereoscopic model is oriented relatively and absolutely to conventional control surveyed on the ground for mapping purposes. Projector B (Fig. 2) containing diapositive No. 2 should occupy the center of the X-bar so that the cone of projection is visible on the table top. The tracing table index should be locked and not changed during triangulation.
   b. Record three pass points on the glass plate which will be on the leading edge of the stereoscopic model. One of the points must be near the flight azimuth and its use is more critical as to elevation than horizontal definition. The other two pass points, one near each corner of the stereoscopic model, are important as horizontal control bridging points and should be sharply defined.
   c. Disconnect the telescoping guide rod of the illuminating light of projector B from the tracing table and guide this table to each of the nine marked areas projecting them on the table top. Carefully mark each of their positions on the scale stable base sheet (Fig. 3).
2. The exterior orientation of this diapositive is now recorded. The only case in which these marked points will again correspond to their projected positions is when the photographic plate is in its original relationship to the working surface of the instrument table plane.
3. Recovery of the exterior orientation may now be made in the following manner:
   a. Rotate both projectors 180° (Fig. 4). Remove diapositive No. 1. Diapositive No. 3 may now be placed in projector A (Fig. 5) without disturbing the interior orientation of diapositive No. 2. Perform a normal relative orientation.
   b. Rotate the manuscript 180°. Disconnect the guide rod of projector B and observe once more the pattern of crosses as recorded after the initial absolute orientation.
   c. Adjust the X-bar, using the three suspension screws until the projected marks again fit their plotted positions (Fig. 6). The base sheet should be oriented to the radial center cross and a double correction applied to each of the 4 points, marked P (Fig. 1), and this is accomplished by reorienting on the radial center each time. When these 5 points agree, check the 4 corner points and apply minor corrections. If all 9 points do not fit, go back and check for residual Y-parallax.

Figure 3. Recording the exterior orientation.

Figure 4. Rotating the projectors.

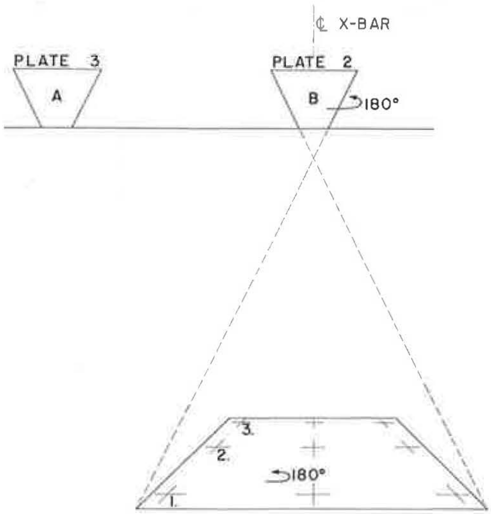


Figure 5. Rotation of projectors.

d. Reconnect the guide rods of the illumination lamps and observe the center pass point stereoscopically. Adjust the air base with the scaling (X-motion) knob until the previously marked elevation is read. If this correction can be applied without moving the center projector, absolute orientation is achieved. If the center projector has been moved, however, the sheet must be reoriented.

4. The next step is minor adjustments.

a. Measure the elevation of the pass point in each corner of the stereoscopic model and make orientation adjustments to bring them to their proper elevation at the scale of the stereoscopic model. To do this, use the leveling screws and scale adjustment, but do not change the tracing table index.

b. Recheck the projected marks and horizontal pass points. When all of these factors agree, absolute orientation is completed.

5. After securing the scale stable sheet to the working surface of the table, the instrument operator selects a series of suitable photographic images to serve as vertical and horizontal pass points to serve as supplemental control points to each of which he

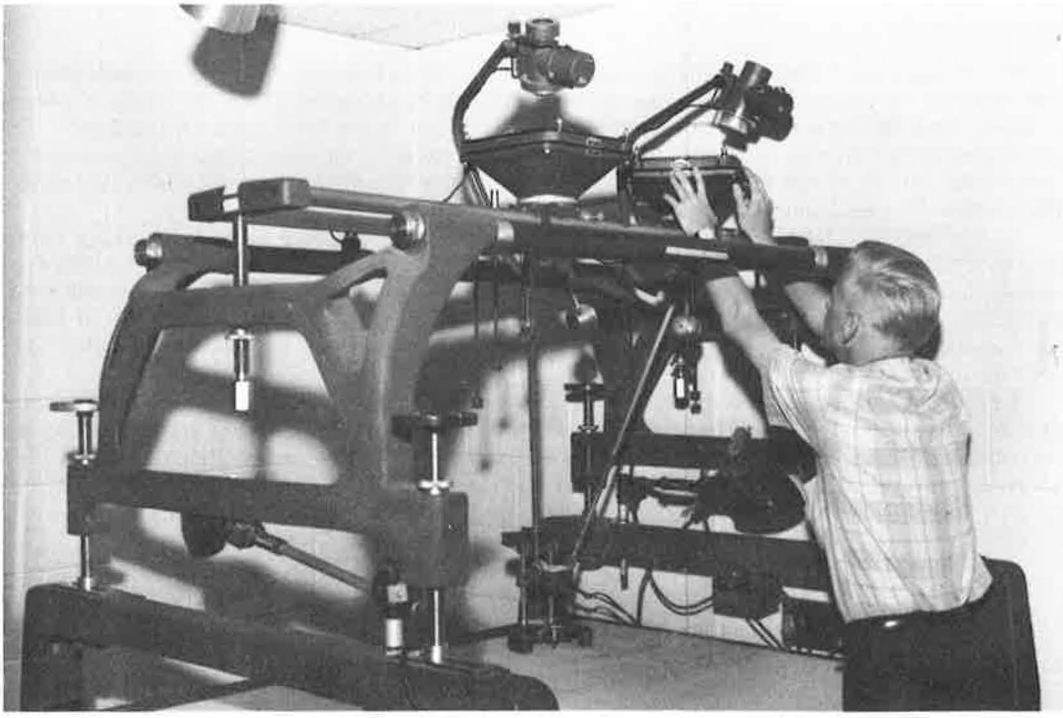


Figure 6. Recovering the exterior orientation.

applies an identification mark on the photograph, and also marks its position on the base sheet along with the radial center of each diapositive. It is desirable, for adjustment purposes, to select points for vertical control where all points will be nearly the distance from the azimuth of the photographic flight line.

6. Before transcribing the succeeding orientation from plate No. 3, both projectors of the instrument must be moved so projector A occupies the center of the X-bar. Absolute orientation is repeated using the control points marked on the base sheet before the cross marks on the next diapositive being used are recorded on the base sheet. This step is essential so all cross marks on this diapositive will be projected on the working surface of the table top at one time.

The instrument operation procedure outlined is repeated for each succeeding diapositive to the match edge of the terminal or controlled stereoscopic model.

The stereoscopic models should not be adjusted to conform to scattered field survey control points encountered in the photographic strip before all work is completed to the end of the bridge. Similarly, no attempt should be made to correct for errors observed in the terminal model. It is from these errors, which are measured and noted in horizontal position and in elevation, that adjustment begins.

This method is based on the assumption error has not been eliminated but controlled, insomuch as it has been cumulated in a systematic manner. The only errors which can be corrected are systematic, therefore the ability and concentration of the stereoscopic instrument operator is of primary importance. Major accidental errors will disrupt the bridged control in an easily identifiable way, eliminating danger of endeavoring to compile maps using extremely erroneous supplemental control data.

The vertical error is caused by a multitude of factors, including lens characteristics, flatness of the working surface of the table top, and human perception. Photogrammetric instrument operators should not be changed during any phase of photogrammetrically bridging to establish needed supplemental control, as resolution of Y-parallax has the greatest effect and is subject to individual interpretation.

ADJUSTMENTS FOR REDUCING ERRORS

Horizontal

The horizontal error is a direct result of the vertical error. The points selected for vertical bridging of control rise as the bridging is extended along the strip of photographs, thus the error is increasingly positive. This tends to displace horizontal positions back towards the beginning of the strip, causing an increasing shortness in horizontal length of the bridge. Consequently, reduction of the raw data is begun with the horizontal positions rather than the vertical error.

As previously stated, the horizontal error cumulates directly at an increasing rate, therefore it is necessary to correctly apportion the ultimate error among the stereoscopic models of the photography strip. This correction is more accurately measured vertically than horizontally, thus a standard procedure used in bridging by use of Multiplex aeroprojectors was adapted to this problem of bridging by use of Kelsh double projection instruments (2).

A straight line should be drawn on the base sheet (Fig. 7) through the radial centers of the first and last diapositives used in the photogrammetric bridging strip. Select a coordinated horizontal point on the initial stereoscopic model and on the terminal stereoscopic model, referred to for convenience as points A and B. Points A′, B′, and C′ are located on the central axis at the perpendicular of points A, B and C.

Obtain the correction factor, ΔZ, by use of the following:

$$\Delta Z = \frac{H \times E}{L} \qquad (1)$$

in which

$E = A'B' - A'C'$;
$H = A'B'$ / number of stereoscopic models; and
$L = AB$.

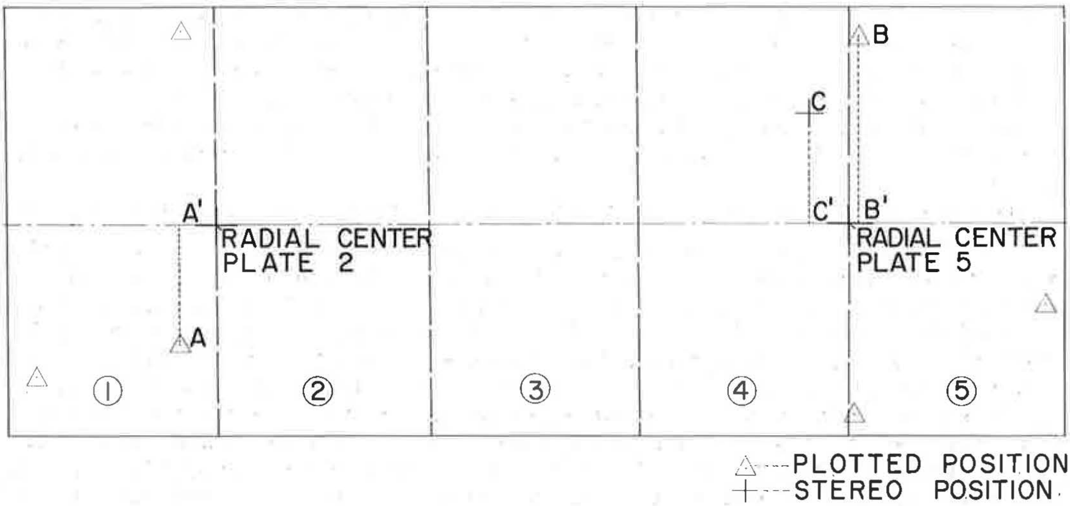


Figure 7. Horizontal plan.

Reset the first uncontrolled stereoscopic model using the unadjusted, bridged control. Subtract ΔZ from the elevation of the center pass point and, by changing the air base, reduce the apparent elevation of the point. Control the swing of the base sheet with the marked position thereon of the radial center and remark from the stereoscopic model onto the base sheet all control points and pass points. Now reset all the bridged stereoscopic models of the photography strip, using the new position of the pass point near each corner of each of the successive stereoscopic models to adjust the base and radial centers to control their swing. As this is done, level each model on the unadjusted vertical control. Prepare an overlay showing plotted point A (Fig. 7) and all stereoscopic pass points. Holding point A, swing point C, making it coincidental with point B. Prick each stereoscopic pass point in its adjusted position on the base sheet. If a significant error in the X direction remains at B, the entire procedure may be repeated until this disparity is removed.

Vertical

Due to the inherent limitations of the Kelsh stereoscopic plotter as an instrument for bridging supplemental vertical control, a graphic solution produced results which were, for all practical purposes, as good as could be obtained. Furthermore, the ease and efficiency of this method recommends it from an economic standpoint.

It might be useful to first describe some of the characteristics of the error which will be adjusted. If the deviation of each bridged point from the correct datum is plotted in its proper horizontal relationship to each preceding point, the successive points lie very nearly on two smooth curves, one for pass points lying on the far side and one for pass points lying on the near side of the trace of the flight line. The two curves are due to error on the Y-axis of the photographic strip which, compounded by the much greater error in the X direction, usually makes it necessary to consider each side of the line of flight separately. The slope of these curves on the graph cumulatively increases because the elements which induce the initial inaccuracy remain constant throughout the operation. Therefore, the final discrepancy is the product of a standard error and the preceding total plus a percentage of the previous error incorporated every time an orientation is recorded.

As in the horizontal adjustment (Fig. 7), it is convenient to locate the points on an instrument coordinate system with the ground trace of the aircraft line of flight as the X-axis. Distances along this line are measured at bridging scale from the first controlled radial center. The line formed by using each pass point near each corner of each stereoscopic model lying each side of the flight line is considered as a unit, usually designated positive and negative, but to avoid ambiguity, referred to herein as red and blue. With direction of the photogrammetric bridge extending from left to the right, the upper half is red, the center line (flight line) is green and the lower half is blue. Points are numbered VR-1, vertical red number one, VB-5 vertical blue number five, and so forth.

The error-curve may now be predicted from the final error in the following manner:

Locate perpendiculars to the bridged vertical control pass points along the central axis. Record the distance to each point and selecting a convenient scale, plot this information on cross-section paper (Fig. 8). Choose a useful vertical scale and plot the observed elevation error of each vertical control pass point from its match edge in the terminal stereoscopic model plotted above its horizontal position on the graph.

Divide, for each vertical control pass point, the graph height of this line into as many equal segments as there are uncontrolled stereoscopic models in the photogrammetric bridge (Fig. 8). With one end of a straightedge at the origin of the X-axis, draw radiating lines through each division on the vertical axis. Mark, either red or blue, the juncture of the appropriate radial center with these radiating lines. A smooth curve through each set of colored points will give the best approximation of the error-curve for the vertical control pass points each side of the flight axis. Center points are corrected midway between the two curves.

In actual practice this method was refined to a "point to point" solution as follows:

The horizontal (X-axis) position and the vertical (Y-axis) position of each point was plotted at the same scale. The origin used for the Y-axis is the furthermost control point (Fig. 9). Lines were radiated from the beginning point of the X-axis through each point on the vertical Y-axis. The appropriate color was marked at the intersection of each radial line with a line drawn vertically at a right angle to the X-axis from the plotted horizontal position of each applicable point on the X-axis. This yields one curve at three vertical scales. To obtain the correction factors, divide the number of small "squares" between origin point of X-axis and each control point into its elevation error. This gives the value, in feet of elevation, for each small "square." The factor for the center points is an average of the red and blue figures. Multiply the height of each point intersection by the proper correction factor to obtain the error in elevation of each bridged vertical control point.

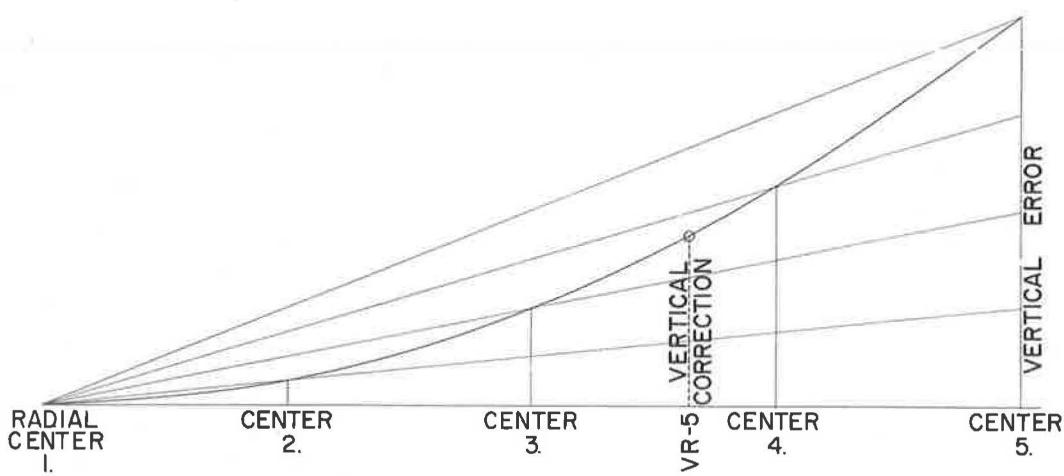


Figure 8. Vertical error curve.

Earth Curvature Correction

If the photogrammetric bridge extends for a long distance, the earth's curvature in feet should be computed by the standard expression:

$$V = 0.167\ L^2 \qquad (2)$$

where L is the length of the photogrammetric bridge in miles.

V can be plotted on an expanded scale in the center of the graph. An arc through V from end to end of the strip provides a simple method of determining this correction for each bridged vertical.

If the photography used is not the "distortion-free" type, an additional correction is required to minimize the effects of lens distortions. The photography used for this test project was taken with a Wild R-C 8 aerial camera, which eliminated the need for considering lens distortions.

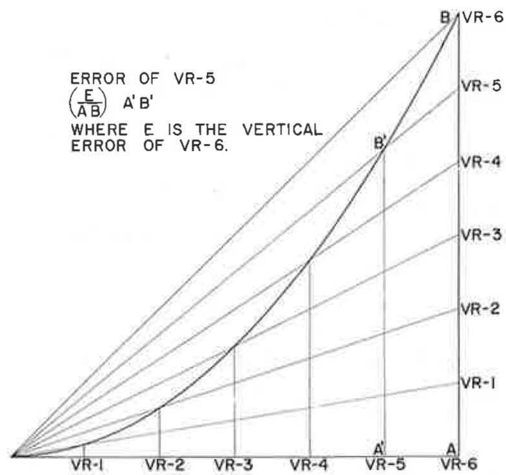


Figure 9. Refined error curve.

RESULTS

Selection of Projects and Scales

The survey projects selected for this investigation were chosen to obtain a variety of topography and photography scales. Every "photogrammetric bridge" was plotted and computed at least twice and the length of several of the bridges was varied a number of times. Each flight strip of photographs selected for the photogrammetric bridging work had been used previously in photogrammetric compilation of maps which had been field checked. After bridging, the elevation ascertained thereby for each vertical control pass point was compared with the elevation measured for it by field surveys on the ground. It may have been possible to achieve better precision with ideally placed ground survey control at a standard distance from the ground trace of the flight line, but position for such control was not selected with bridging in mind. Positioning of the points varied considerably in Y-distance from the flight line.

Horizontal Accuracy

The accuracy achieved in establishing the position of horizontal supplemental control was much better than accomplished for vertical control. At present there is no coordinatograph in Georgia. Consequently, measurement of the errors gave rise to conjecture. Perhaps some of the positional errors were due to slight variations in the plane coordinate grid lines and in plotting the surveyed horizontal control. Aerial photography scale did not have an effect on the real horizontal errors. Thus, large scale photography yields quite accurate results at map compilation scale. In observation of numerous bridged horizontal points throughout the entire test project, the greatest discrepancy noted was less than 0.05 in. at the stereoscopic model scale at which the photogrammetric bridging was done. The error was so minute that it could not be reliably measured with present equipment.

For such reasons, it was not deemed useful to present any more than a representative tabulation of results attained (Table 1). More work should be done with a coordinatograph, to better determine the magnitude of error. In addition, virtually no difference in horizontal accuracy was noted between bridges of 5 and 7 stereoscopic models. How many stereoscopic models can be used between surveyed control points in photogrammetric bridging with double projection instruments and maintain acceptable accuracy has not as yet been determined.

Vertical Accuracy

There are three major factors affecting the quality of the vertical accuracy:

1. Ability of the stereoscopic instrument operator.
2. Length of the photogrammetric bridge in number of stereoscopic models.
3. Calibration of the stereoscopic plotter.

TABLE 1

REPRESENTATIVE TABULATION

Point No.	Error (in.)
1	0.00
2	0.00
3	0.01
4	0.03
5	0.02
6	0.01
7	0.01
8	0.00
9	0.00

Much more precision is demanded of the photogrammetric instrument operator in bridging vertical control than in photogrammetrically compiling conventional topographic maps. In the compilation of topographic maps there is usually an allowable error of plus or minus one-half contour interval. Moreover, the photogrammetric instrument operator engaged in bridging cannot eliminate all error while obtaining supplemental control, thus requiring the subsequent mapping work to be virtually errorless. Therefore, at present, this method of establishing supplemental control does not acceptably fulfill all requirements for much of the large-scale topographic mapping needed for highway design and preparation of detailed construction plans.

The results from bridging supplemental vertical control as subsequently explained and as noted in Table 2 are based on the following aerial photography scales and contour invervals:

Mapping Scale (ft to 1 in.)	Contour Interval (ft)
250	2
500	5
1,000	10

Two lengths were considered for the photogrammetric bridges; control on the first and seventh stereoscopic models and control on the first and fifth. On the longer bridges it was found that 74 percent of the bridged vertical control points were not in error more than plus or minus one-half contour interval and 40 percent not more than plus or minus one-quarter contour interval. For the bridges controlled on stereoscopic models one and five, 98 percent were not in error more than one-half contour and 75 percent more than one-fourth contour interval. It seems likely from these results that control on the first and fourth stereoscopic models would yield dramatically better results.

Extremely small changes in instrument calibration can produce fairly large changes in the unadjusted vertical error. This causes no particular problem if the photogrammetric bridging is completed with little interruption using a well-calibrated instrument. The final error of a single strip bridged twice may double on one of the operations, but the residual error will remain virtually the same, barring accidental error which usually affects single points.

More work needs to be done to prove the reliability of this process in all cases. As previously mentioned, information is lacking on both shorter and longer photogrammetric bridges than reported herein. Consequently, more of such bridging tests should be undertaken using scattered ground control, and smaller and larger numbers of stereoscopic models in each bridge.

TABLE 2

VERTICAL ACCURACY

Photography Scale (ft/in.)	Control Error Less Than (ft)	Control in Stereo Models (%)	
		1 and 7	1 and 5
250	1.5	100	100
	1.25	87.1	100
	1.0	67.7	93.8
	0.75	58.1	93.8
	0.50	41.9	68.8
	0.25	25.8	31.3
500	3.5	87.5	100
	2.0	75.0	100
	1.50	50.0	100
	1.0	25.0	85.7
	0.5	12.5	80.0
1,000	4	--	100
	3	--	83.3
	2.5	--	66.7
	2.0	--	50.0
	1.5	--	33.3
	1.0	--	16.7

CONCLUSIONS

Truly reliable information on cost is unavailable at this stage, but some speculation can be made regarding these experimental projects.

A photogrammetric bridge of five stereoscopic models should require about 30 man-hours of work, including all adjustments to completion. Comparative costs are difficult to compile as costs will vary from place to place. But in Georgia photogrammetric bridging work represents roughly only one-fifth of the normal cost of establishing supplemental control by surveys on the ground.

The most efficient use of photogrammetric bridging of supplemental control would be for block area mapping. The field survey parties must measure a traverse along a highway route comprising a strip area for which control must be established regardless of the number of stereoscopic models, whether or not they are to be bridged. The control traverse measuring comprising a series of parallel strips of aerial photographs, for mapping a broad area, could proceed at a right angle to the direction of the aerial photography strips and cross mapping the project area at the interval of the number of stereoscopic models to be included in each photogrammetric bridge.

The most immediate benefit of this process of photogrammetric bridging has been determination of erroneous field surveyed control. Large vertical or horizontal discrepancies will generally be apparent without adjusting the raw data and smaller errors will be discovered after adjustment.

For stereoscopic models not containing reliable control on which to end the photogrammetric bridge, a form of cantilever extension may be employed. Set up the stereoscopic model preceding the last reliably controlled model. Now bridge the controlled model and observe the amount of vertical error apparent at the extreme edge. Correct this error and bridge the questionable models, applying the same correction after each bridging operation. In some situations, determining which of several control points should not be used can eliminate sending a field survey party back to an area to make essential checks.

Other areas of application might be:

1. Small-scale topographic mapping.
2. Horizontal bridging using field surveyed vertical control.
3. Planimetric mapping.

Results achieved thus far suggest continuation of this test project. Many answers obtained point the way to further variations in technique. Better results are expected as the photogrammetric investigations using double projection instruments are continued.

REFERENCES

1. Gunn, A. C., "A Triangulation Technique for Use with the Kelsh Plotter." Photogrammetric Engineering, XXI:3, 341-343, (June 1955).
2. "Multiplex Mapping." Department of the Army Technical Manual, TMS-244, 60-61 (June 1954).