ECONOMIC POSSIBILITIES OF HIGH STRENGTH LOW ALLOY STEEL IN HIGHWAY BRIDGES

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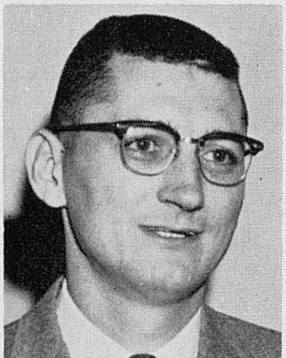
The economy of the use of high strength alloy steels in long span highway bridges is an accepted fact. The economic possibilities of the use of these steels in short and medium span highway bridges has not been fully investigated. This is a summary of progress on a study of the economic use of nickel-copper corrosion resistant high strength low alloy steels in short and medium span highway bridges which is underway at Purdue University in co-operation with The International Nickel Company, Inc.



Grades of Structural Steel Considered

Steels conforming to the following standard specifications were used; ASTM designations A7, A373, A36 and A242.

The specifications for ASTM A7 structural steel, commonly called structural carbon steel, were first issued in 1936. Only mechanical properties are specified with no requirements on chemical composition. The minimum yield point is 33.0 kips per square inch (ksi) in all thicknesses. This steel has been primarily used for riveted construction in bridges, although building specifications permit welding of A7 structural steel.

The specifications for ASTM A373 structural steel were first issued in 1954 to provide a steel for use in welded highway bridges. Requirements are specified on chemical composition as well as mechanical properties to insure weldability with normal techniques and procedures. The minimum yield point is 32.0 ksi in all thicknesses.

The specifications for ASTM A36 structural steel were issued in 1960 to provide a higher strength carbon steel. Requirements are specified on chemical composition as well as on mechanical properties. The welding of this steel is permitted by building specifications, but as of this date (February 1962) it has not been classified as a weldable steel for highway bridges. The minimum yield point is 36.0 ksi in all thicknesses.

The specifications for ASTM A242 structural steel were first issued in 1941 to provide a high strength low alloy steel. Mechanical properties are specified. Requirements on chemical composition are variable and may be stipulated so as to increase atmospheric corrosion resistance and render the steel weldable. The minimum yield point varies from 42 ksi to 50 ksi, depending upon the thickness of material.

Purpose of Study

The objective of the work at Purdue University is to investigate the economic possibilities of nickel-copper high strength low alloy steels in short and medium span highway bridges.

A report has been published[1] on the first phase of the study, which was analytical comparisons of the designs for the superstructures of typical short span concrete slab and rolled wide flange steel stringer highway bridges fabricated from nickel-copper high strength low alloy steel with those fabricated from ASTM A7 or A373 structural steels. The results of this first study indicate that this type of highway bridge may, for all practical purposes, be constructed of nickel-copper types of high strength low alloy steels at about the same first cost as if A7 or A373 structural steels were used.

The second phase of the study was an analytical investigation of the comparative economic use of various steels for welded I-section stringers with concrete deck for short and medium span highway bridges. The results indicate that structures of this type may be fabricated and erected using a nickel-copper grade of high strength low alloy steel at about the same first cost in dollars as if A373 structural steel were used.

A paper summarizing this phase of the study, entitled "Economic Possibilities of Corrosion-Resistant Low Alloy Steel in Welded I-Section Stringer Highway Bridges", was presented at the 41st Annual Meeting of the Highway Research Board, held in Washington, D.C. January 8-12, 1962. It will be published in the proceedings of the meeting.

The third phase of the investigation, a study leading toward the application of nickel-alloy steels to new forms of highway bridges, is now in progress.

Details of Design

Since the objective of the first and second phases of the study was to make comparative designs in the various steels, the details of the structures used for the comparative analyses were made as generally acceptable as possible. A 30-foot clear roadway was used with details approximately as found in the Bureau of Public Roads, U. S. Department of Commerce, *Standard Plans for Highway Bridge Superstructures*, revised 1956. The structures considered in phases 1 and 2 were designed in accordance with the American Association of State Highway Officials (AASHO), *Standard Specifications for Highway Bridges*, 7th edition, 1957.

Typical cross sections of the structures considered in the first phase, a study of rolled wide flange stringers with concrete slab, are shown in Figure 1.

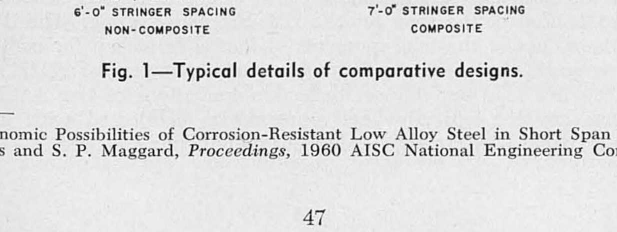


Fig. 1—Typical details of comparative designs.

[1] "Economic Possibilities of Corrosion-Resistant Low Alloy Steel in Short Span Bridges", by J. M. Hayes and S. P. Maggard, *Proceedings*, 1960 AISC National Engineering Conference, pp. 59-68.

Typical cross sections of the structures considered in the second phase, a study of welded I-section stringers with concrete slab, are shown in Figure 2.

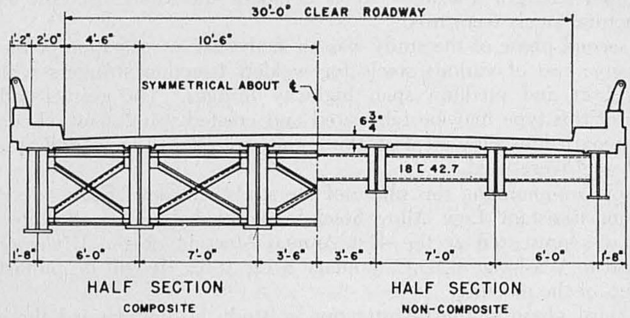


Fig. 2 Typical details of comparative designs.

Assumptions Made in Comparative Designs

The structures were designed for the H20-S16 live loading in accordance with the AASHO Bridge Specifications.

The composite designs were made in accordance with the AASHO Bridge Specifications, and the following additional assumptions: (1) All dead load, including future wearing surface, carried by steel alone; (2) Bottom of concrete slab at top of top flange. No attempt was made to vary the size of the flange plates along the length of the span. Since comparative designs were all that was desired, it is thought that this is permissable. It is considered that these assumptions give sufficiently accurate results for comparative estimates using the various steels.

Deflection Limitations

Section 1.6.10 of the AASHO Bridge Specifications limits the deflection due to live load and impact to 1/800 of the span. This deflection may be computed for the standard loading considering all stringers as acting together and having equal deflections, if the diaphragms are sufficient in depth and strength to insure lateral distribution of loads.

Figure 3 is a plot of the required minimum sum of the moments of inertia of all the stringers in a simple span to maintain the specification deflection limitation of 1/800 of the span for the H20-S16 live loading and impact effect. Also shown are the required minimum sums of the moments of inertia of all the stringers in a simple span to maintain the live load plus impact deflection at both 1/1000 and 1/1200 of the span for the H20-S16 live loading. The dashed lines represent the values of the total moments of inertia furnished for both composite and non-composite designs for rolled wide flange stringers of A242 steel. It is seen that the live load and impact deflection limitations of the AASHO Bridge Specifications are not critical where stringers are fabricated with wide flange sections rolled from A242 steels, if adequate diaphragms are used.

Similarly, in Figure 4, the dashed lines represent the total moments of inertia furnished by the welded I-section stringer designs. Both composite and non-composite designs are shown for the A242 steel, and the composite designs are shown for A373 steel. Again, it is seen that the live load and impact deflection limitations of the AASHO Bridge Specifications are not critical with the welded I-section stringer fabricated from A242 steel, if adequate diaphragms are used in order that full live load and impact deflection may be equally distributed to all stringers.

Comparative Quantities

Comparative designs were made for the rolled wide flange stringer and concrete slab structures at two foot intervals from a 64 foot span to the maximum simple span length permitted by the span-depth limitations of the AASHO Bridge Specifications—about 76 feet for non-composite action and 94 feet for composite action. This increment was used in order to take into consideration the variation in the efficiencies of the rolled wide flange sections available for

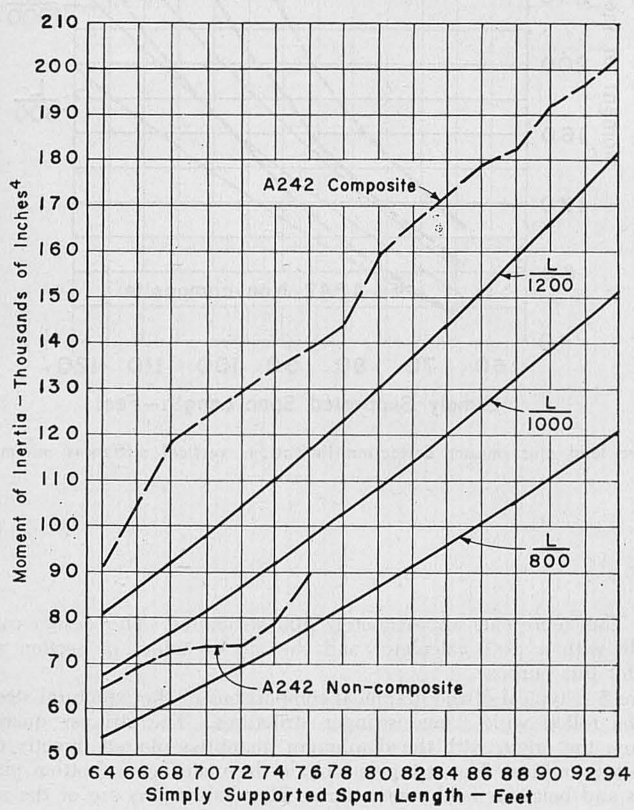


Fig. 3—Live load plus impact deflection limitations 7 ft. stringer spacing.

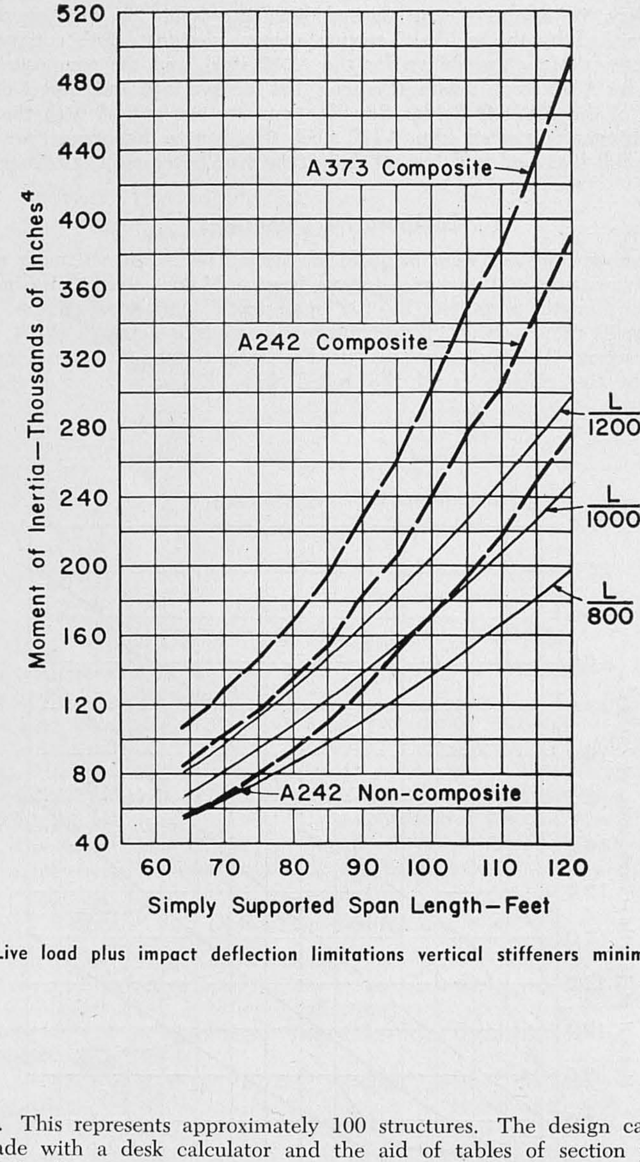


Fig. 4—Live load plus impact deflection limitations vertical stiffeners minimum depth stringers.

stringers. This represents approximately 100 structures. The design calculations were made with a desk calculator and the aid of tables of section properties prepared for this purpose.

Figure 5 is typical of the graphical comparisons of the structural steel quantities for the rolled wide flange stringer structures. The stringer quantities are plotted from the origin with the diaphragm quantities plotted directly on top of the stringer quantities. The stringers include the main beam, bottom plate, bearing details and bolts for field connections. The diaphragms are of the same type of steel as the stringers. The A7 steel quantity is shown on the left and that of the A242 steel is shown on the right for each span grouping.

For the welded I-section stringer and concrete slab structures, comparative designs were made for span lengths of 64 and 68 feet, and at five foot intervals from 70 to 120 feet in both composite and non-composite action. Designs were made at all span lengths for the minimum permissible depth allowed by the span depth ratios. Designs were also made for the following depths based on web buckling ratios: (1) maximum permissible depth for a 5/16 inch web of A242 steel; (2) maximum permissible depth for a 5/16 inch web of A373 steel; and (3) maximum permissible depth for a 7/16 inch web of A242 steel. It is thought that this gives a good bracketing coverage of possible depths for comparative purposes. This represents about 400 structures. The design calculations were made with an electronic computer.

Figure 6 is typical of the graphical comparisons of the structural steel quantities for the welded I-section stringers. The quantities include bearings, diaphragms, stiffeners and weld material.

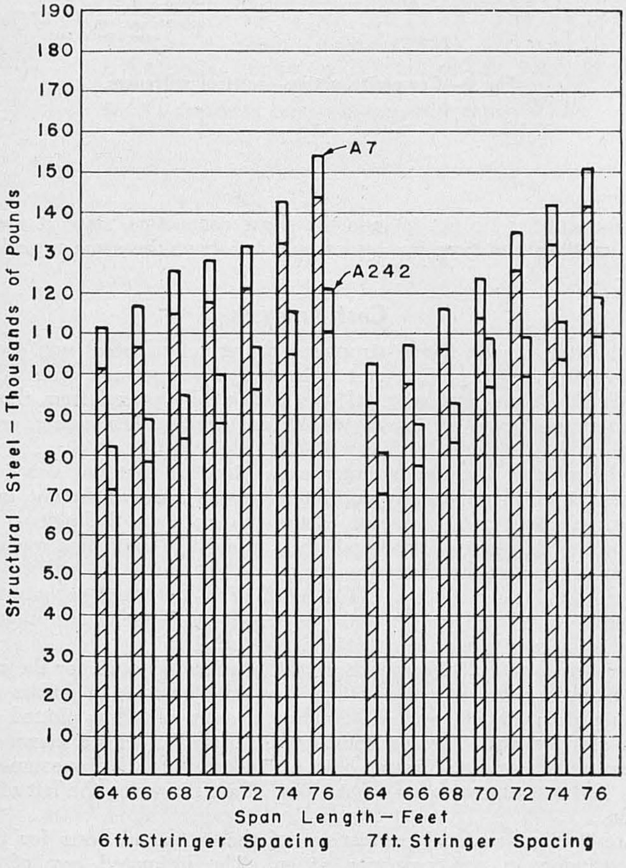


Fig. 5—Structural steel—non-composite action.

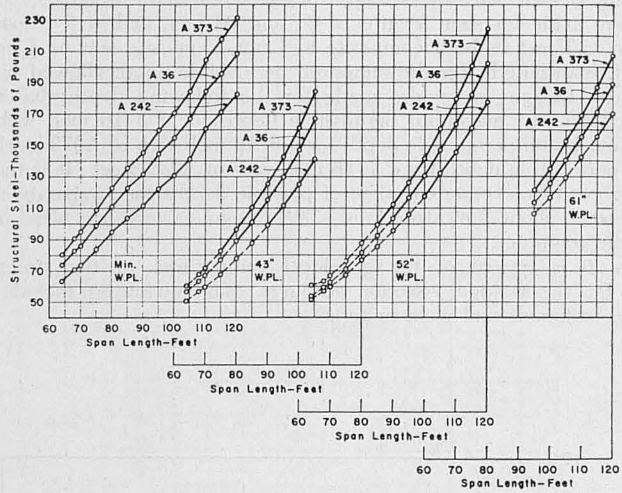


Fig. 6—Composite action—vertical stiffeners.

These quantities do not include the shear connectors, since it was assumed that the quantities and type involved would be about the same regardless of the steel used.

Cost Analyses

For the rolled wide flange structures the structural steel was grouped into two divisions for the purpose of cost estimates. These groups were stringers and diaphragms. Each piece of material was individually priced from the mill base with appropriate charges for extras, freight, engineering, fabricating, erecting and painting.

For the welded I-section stringer each piece of material was individually priced from the mill base with appropriate charges for extras, freight, engineering, fabricating, erecting and painting. After pricing each individual piece and determining the total cost of structural steel, an average unit price was determined and used in computing the cost estimates.

The cost analyses made for ASTM A242 steels are based on only those types which contain nickel and copper and provide an atmospheric corrosion resistance recognized to be four to six times that of carbon steel.

Figure 7 is a graphical comparison of the estimated costs for the rolled wide flange stringers in non-composite action. The stringer costs in dollars are plotted from an origin of $10,000, with the diaphragm costs in dollars plotted directly on top of the stringer cost. The cost estimates for the A7 steel are shown on the left of each span comparison. Figure 8 is a similar plot for the composite action stringers. The cost estimates for the A373 steel are shown on the left of each span comparison.

Figure 9 is a graphical comparison of the estimated costs for the welded I-section stringers in non-composite action. The estimated cost of the A373, A242 and A36 steels are shown by the left, middle, and right bars respectively

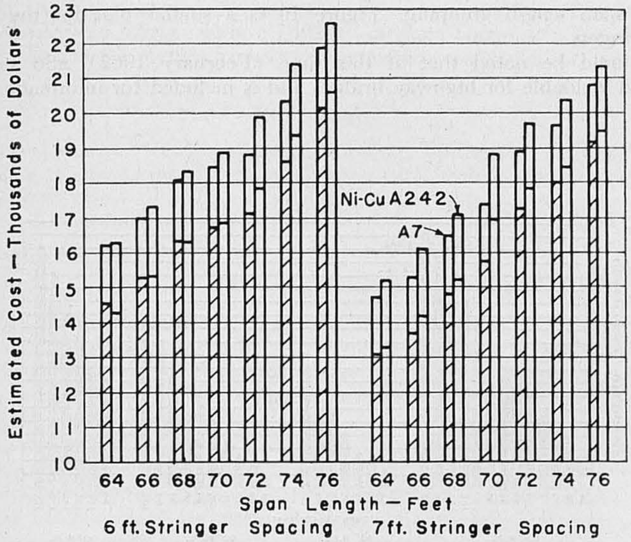


Fig. 7—Estimated cost—non-composite action.

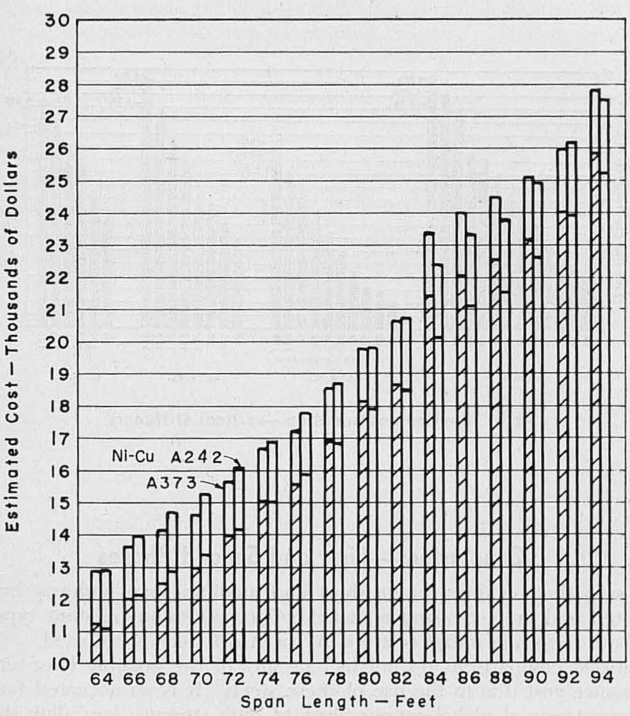


Fig. 8 Estimated cost—composite action 7 ft. stringer spacing.

for each span length grouping. Figure 10 is a similar plot for the composite action stringers.

It should be noted that at this time (February 1962) A36 steel is not considered weldable for highway bridges and is included for information only.

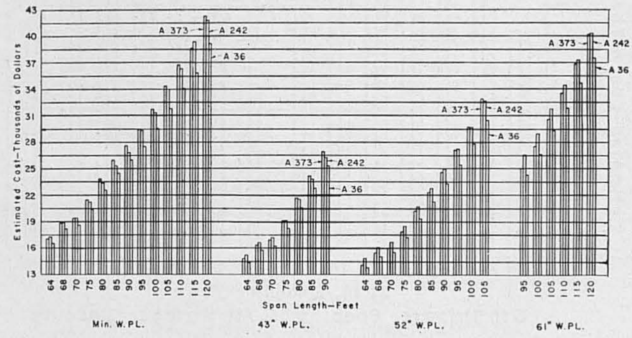


Fig. 9—Non-composite action—vertical stiffeners.

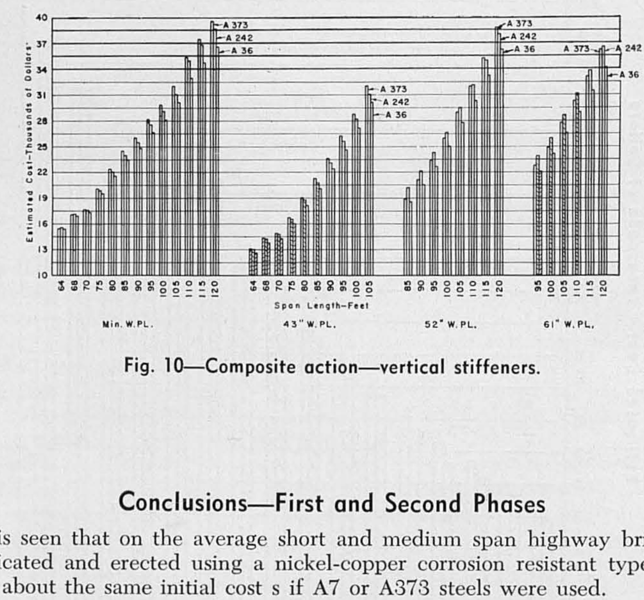


Fig. 10—Composite action—vertical stiffeners.

Conclusions—First and Second Phases

It is seen that on the average short and medium span highway bridges may be fabricated and erected using a nickel-copper corrosion resistant type of A242 steel at about the same initial cost s if A7 or A373 steels were used.

These cost comparisons do not include any of the possible long term savings in maintenance cost due to the use of these steels. It is an accepted fact that the corrosion resistance of nickel-copper types of high strength low alloy steel is four to six times that of structural carbon steel. Furthermore, many investigators have established the fact that any improvement in the corrosion resistance of steel produces a beneficial effect on the durability of paint coatings.[2] This may be an important factor in the study of economic maintenance of structures.

Third Phase

The third phase of this investigation is a study leading toward the application of alloy steels to new forms of highway bridges. It is being conducted outside the range of current standard design specifications. The objective is to develop more economical details for highway bridge construction utilizing alloy steels, with emphasis upon the special properties of corrosion resistant types.

The two avenues of approach to improvements in the economy of highway bridge construction are: (1) the development of refinements in present practice, and (2) the development of new concepts and structural configurations. A combination of these two procedures may offer the best approach to the improvement in overall economy of design, fabrication, erection and maintenance.

Economy in highway bridge construction may be obtained by more efficient structural use of the supporting steel—the full utilization of every ounce of steel. This means design for the complete integrated structural action of the component parts of the bridge superstructure. Composite action between a concrete slab and the steel stringers is an example of partially integrated structural action.

Further economy may be obtained through the maximum of shop prefabrication which usually results in the best overall economy. There is also the possibility of savings with the integrated use of the various grades of structural steel.

These studies are being conducted and the data reported in the hope that they may be of assistance to highway bridge engineer in designing structures with the best overall economy in design, fabrication, erection and maintenance for the specific site.

Acknowledgments

These studies are being conducted in the Engineering Experiment Station, Purdue University, Lafayette, Indiana, in cooperation with The International Nickel Company, Inc., New York, New York. The authors gratefully acknowledge the assistance of Mr. Joseph O. May, Consulting Engineer, Ridgewood, New Jersey, for his assistance in making the cost analyses, and wish to thank Mr. L. Anselmini of The International Nickel Company, Inc., for his assistance in the investigations.

[2] *Ibid*, p. 66.