# Conquest of the Darien

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•SINCE THE discovery of America and the early explorations of this hemisphere, a means of connecting North and South America by land transportation has been the dream of explorers and engineers. This dream is now near realization.

Almost 100 years ago a formal project for uniting the Americas by land communication was proposed in the U.S. Congress. All attempts to do so, however, have been frustrated by the inaccessibility of the vast jungle region adjoining the Republics of Panama and Colombia in what has become known as Al Tapon Del Darien—the Darien Gap. The earliest studies in the Darien area for possible routing of a land connection between the continents encountered the tremendous Atrato River swamps in Colombia, and, understandably, subsequent explorations eliminated the swamps from further consideration. It was generally concluded that any rail or highway route crossing the Atrato River swamps would indeed be interrupted by a canal some 20 miles long. These early explorations had been limited to the local areas adjacent to the Atrato River swamps where great depth of unstable materials was encountered, and crude probings resulted in the description of these swamps as "bottomless." The highway route reconnaissance circumnavigated the swamp areas, resulting, by process of elimination, in the most southerly location being recommended for the Pan American Highway. Subsequent funding for surveys by the Pan American Highway Congress led to definitive studies for this southern route.

The Bureau of Public Roads, recognizing the tremendous savings that could be realized through a routing of the Pan American Highway across the Atrato River swamps—a line some 200 miles shorter—insisted upon questioning all previous assumptions that they were indeed impassable. After numerous diplomatic exchanges the Bureau was successful in negotiating an agreement with the Colombian Minister of Public Works permitting reconnaissance surveys to be undertaken in 1964. This paper describes these studies and the subsequent detailed geophysical surveys carried on under the direction of the Bureau of Public Roads. This work, which has just been brought to a conclusion, assures a saving in construction cost estimated in excess of $100 million.

Few maps of any type were available for planning detailed investigations of topographic and ground conditions of the Atrato swamps, and no maps of suitable scale and detail were available for acquiring survey data. The most formidable problem confronting the Bureau of Public Roads involved the logistics of providing access and support for field crews. The Atrato River swamps are approximately 65 to 100 km wide and more than 250 km long. The Bay of Colombia at the south end of the Gulf of Uraba is gradually being filled from the west by the numerous delta outlets of the Atrato River. The closest approach to this area is through the small shipping port of Turbo on the Gulf of Uraba, which is the north terminous of the highway leading from Bogota and Medellin called The Highway to the the Sea (Fig. 1).

Beginning in 1964 the Bureau made a thorough search of all likely sources of aerial photography, and partial photographic coverage was assembled with the assistance of the Army Map Service, the Defense Intelligence Agency, the Colombian Ministry of Public Works, and the Inter-American Geodetic Survey. Photography from these sources ranged in scale from 1:30,000 to 1:50,000. Quality of the photography varied

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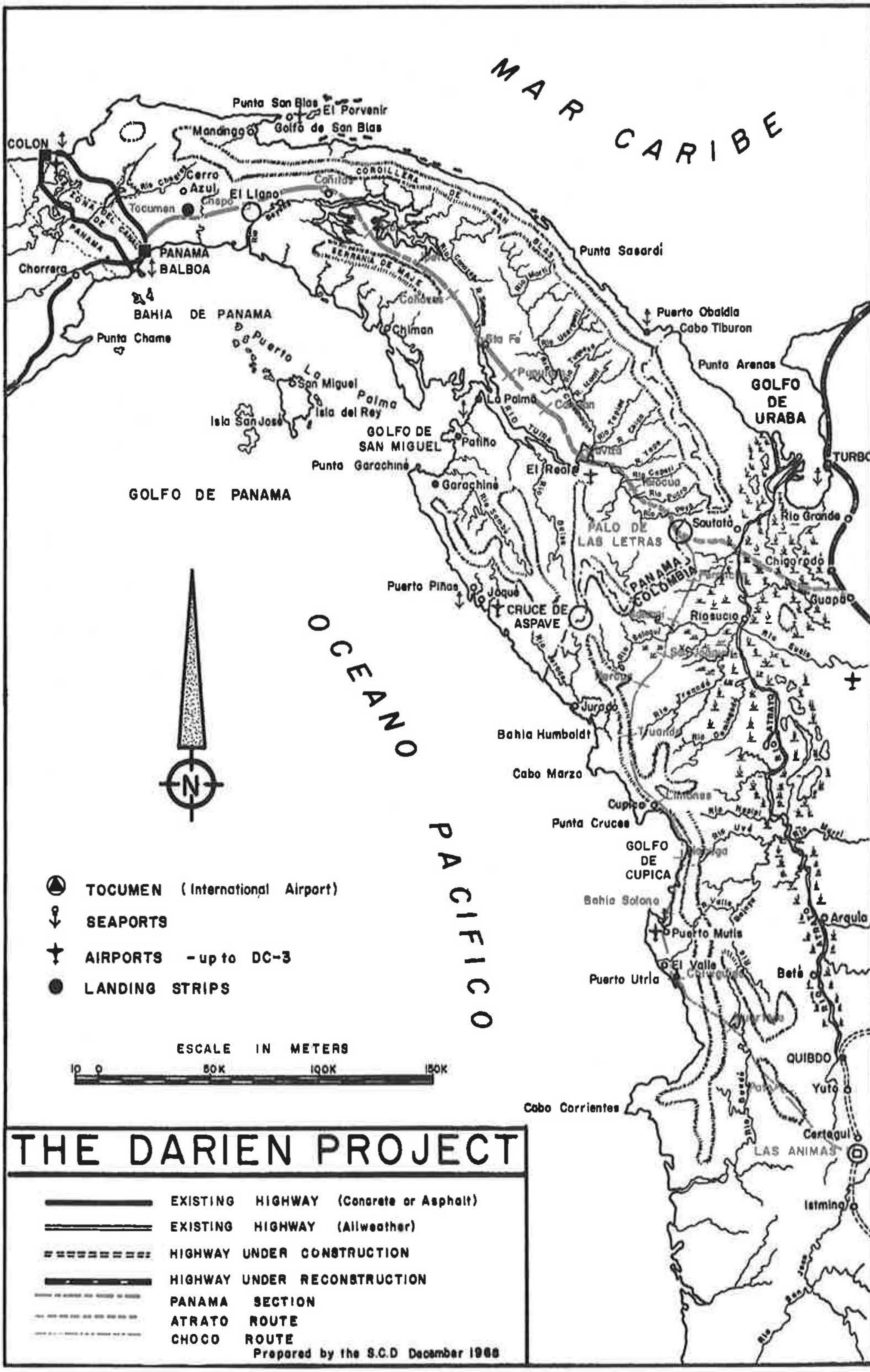


Figure 1. Location of the Darien Project.

extensively, and most included scattered cloud formations that totally obscured significant areas. Additional aerial photography had to be obtained and was provided through a joint operation wherein the Colombian Ministry of Public Works furnished the Ministry's plane and the Bureau furnished the equipment and technicians.

Stereoscopic examination and photographic interpretation of these uncontrolled early photographs led to the selection of five possible route locations that met the criteria established for the least difficult crossings of the swamp. A control point affecting all route locations was the crossing of the Panama-Colombia border at Palo de las Letras because this crossing had been specified by treaty between these countries.

The five selected routes were delineated on the uncontrolled photomosaic that had been assembled with all pertinent information shown. Comparative interpretation of the five tentative routes was then planned under a research project involving the application of aerial infrared imagery. The usefulness of infrared imagery for obtaining subsurface information in tropical areas had never been established; however, it was known that remote radiation sensing and scanning equipment had produced successful interpretive imagery in other areas.

A contract was negotiated with H. R. B. Singer, Inc., State College, Pennsylvania, with the expectation that small thermal anomalies could be detected and usable infrared imagery of the large swamp area would permit interpretation of subsurface foundation conditions. It was our hope that such detailed analysis of the extensive swamp area from the air would eliminate the need for prolonged and costly investigation and surveys on the ground.

A twin-engine Beachcraft was flown from Pennsylvania to Turbo, Colombia, where the thermal sensing and infrared imagery-producing equipment was installed. Because infrared imagery is best obtained at night, the test flights were made during the full moon period of February 1965 from the small airfield at Turbo by a brigade of lantern-toting natives. Regrettably the infrared imagery obtained did not contain sufficient thermal differences to reveal subsurface conditions and materials. It was generally accepted that the factors of intense humidity, very slight temperature differential between day and night, and the lack of sharp contrast of swamp materials contributed to this failure.

Our only alternative then was to work on the ground in the swamp where the best means of access proved to be by helicopter. The five previously chosen routes were given close inspection from low altitude helicopter flights and limited inspection on the ground when a helicopter landing could be made. Such landings involved lowering of machete men by cable first to cut the deep swamp vegetation that rose to a height of 12 to 15 ft. This visual examination of surficial conditions, supplemented by meager peat sampler penetration into the swamp wherever the helicopter landings were made, led to the elimination of four of the five routes. More extensive studies were concentrated on the one that offered the most promise. This route originates at the border crossing point of Palo de las Letras and extends southeastward to the edge of the swamp at a point near the mouth of the Cacarica River. From there it continues eastward in a straight line across the narrowest part of the entire swamp (approximately 22 km) to a series of small lomas or hills from which point the route extends easterly to a connection with the existing Turbo-Medellin Highway, 4 miles north of Guapa (Fig. 2).

Once the specific route had been recommended, a very limited geophysical survey was undertaken, utilizing electroresistivity methods augmented by soundings with a peat sampler and by probing. It was necessary that all personnel and equipment be lifted by helicopter to successive study sites where machete crews had to clear a resistivity corridor across the proposed line. Sufficient resistivity tests were made to substantiate that a relatively stable sandbase containing some sodium chloride existed some 20 to 35 ft below the swamp surface. The salt-laden sediment comprising an old seabed layer was interpreted from the significant downtrends in the resistivity depth curves.

Summing up the conclusions drawn from these limited tests, the Bureau of Public Roads reported to the Pan American Highway Congress that the highway crossing of the swamp appeared feasible and that the tremendous savings indicated by such a location

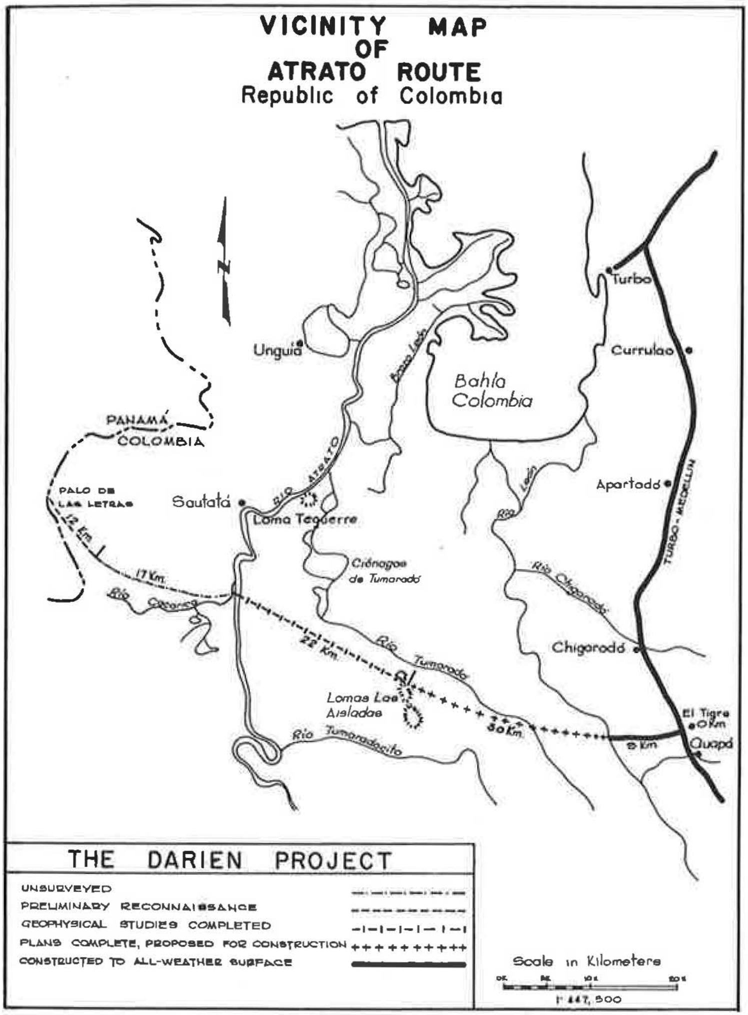


Figure 2. Highway route through Atrato River swamps.

justified the undertaking of more extensive geophysical studies for the development of a realistic design and cost estimates.

In 1967 the Darien Subcommittee of the Pan American Highway Congresses provided funding and requested the Bureau of Public Roads to direct the comprehensive geophysical studies of the Atrato area. The Bureau, in coordinating this program, set an outstanding example of international cooperation. Participating in the work were the following:

Colombia—Federal Ministry of Public Works; Engineer Corps., Colombia Army; Antioquia Department of Public Works; Petroleum Helicopters de Colombia, S. A.; and Solingral Laboratory of Medellin.

Panama and the U.S. Canal Zone—Atlantic-Pacific Interoceanic Canal Study Commission; Corps of Engineers, U.S. Army; Gorgas Hospital; Inter-American Geodetic Survey; and Panama Canal Company.

United States—Bureau of Public Roads, Regions 3, 8, and 15, and Washington, D.C.; and Law Engineering Testing Company, Atlanta, Georgia.

Organization of American States—The Darien Subcommittee staff and field forces.

A Bureau of Public Roads evaluation team, in consultation with a representative of the Law Engineering Testing Company, developed all plans for the entire program of geophysical investigation, recognizing the limitation of time (operations could only be accomplished in the dry season, February 15 through April 30), personnel available, and funding. This evaluation group participated in the field studies, interpreted all findings, and submitted final recommendations to the Darien Subcommittee.

## FIELD WORK

Field work was started in January 1968 on the machete clearing for centerline and cross-sectional trochas and some 22 heliports in the area, on installation of base camps and assembling of all necessary field study equipment and fuel for helicopters, and on the many difficult logistical preparations necessary for the concentrated surveys.

## BORING AND SAMPLING

Boring operations commenced early in February and followed the procedures outlined in the ASTM Method D 1586. Light Acker tripod wash-boring equipment was used for eight borings, spaced equally across the swamp. The drill rig was mounted on prefabricated wooden platforms, supported on oil drums that had been transported to the test locations by helicopter. Drilling water in large quantities was obtained from pits cut in the root mat of the swamp.

Undisturbed sampling of the peat and root mat was extremely difficult. In a number of instances the thin-walled 2.5-in. OD steel sample tube was forced through the root mat more than 10 ft, yet a sample only 18 in. long was recovered. In most cases these samples comprised the more fibrous portion of the organic material.

In all probability, densification or precompression was induced by the sampling operation of the organic mat. In the deeper silts and clays that are saturated, it is unlikely that any change in density occurred during the sampling. Instead, it is possible that some slight degree of disturbance occurred. Undisturbed sampling of the softer silts with sand seams was exceedingly difficult, and samples were not always recovered in these materials. However, a study of the boring records indicates that the undisturbed samples that were secured were representative of the total spectrum of materials beneath the swamp surface. All samples were sealed in the tubes immediately after sampling.

Borings on potential borrow sources in the Lomas Las Aisladas and in the hills west of the Atrato River were made using a Joy No. 7 rotary core diamond drill. The borings on the banks of the Atrato River were first advanced 60 to 70 ft by light tripod equipment and from that depth to final penetration by the Joy No. 7 core drill.

The deeper materials were identified from the cuttings washed to the surface, and the resistance of the materials was estimated from the penetration of the chopping and washing bit. Strength or resistance of the materials did not vary appreciably below 100 ft until hard materials were reached at substantially greater depth.

In the borings on the river banks, rocklike materials were reached at a depth of approximately 145 ft. In both cases diamond core drilling was commenced at these levels using BXM core barrels. In neither case was much core recovered because of the softness of the material drilled and probably because of the mechanical limitation of the lightweight drilling equipment at these great depths. However, small segments of core were recovered, indicating fine-grained sandstones and claystones. Complete logs of each boring were kept, including location and type of samples, drive penetration, and vane shear test data.

## ELECTRICAL RESISTIVITY STUDIES

Electrical resistivity tests were performed along the centerline and cross-sectional trochas throughout the swamp, in all potential borrow areas, on the banks of the Atrato River, and, by use of a considerable flotilla of boats and canoes, in the river itself. A total of 163 such tests were made.

A simple milliammeter-potentiometer resistivity apparatus was used, employing direct current and using porous porcelain pots in the potential circuit. During a depth test, the four electrodes used were spaced an equal distance apart—3 ft, 6 ft, 9 ft, and so on—as the test proceeded, the assumption being that the spacing was the depth involved. The resistivity obtained was plotted against the electrode spacing or depth to produce a resistivity-depth curve showing trends to higher or lower resistivity as the test involved deeper portions of the subsurface and, thus, signifying subsurface layer changes.

The resistivity determinations do not necessarily indicate the engineering character of the soil to rock. Instead, they measure the degree of ionization of the soil or rock materials and, particularly, the ionization of any water in the pores. Therefore, a boundary of different resistivities may not always coincide with a boundary between strata of different engineering properties. This is particularly true in formations consisting of interfingered layers—sands and clays with varying amounts of salt left over from the deposition of the soils in the sea and with varying amounts of organic matter whose decomposition produces organic acids. In the swamp and along the river bank, therefore, the greater reliance was placed on the direct evaluation of the soil properties by borings and by laboratory tests of the materials below the organic zone where the resistivity changes may not reflect the engineering property differences.

## SEISMIC TESTS

Refraction seismic tests were made in the hills at both ends of the line, at the river crossing, and at one location in the swamp. The work was done using a 12-channel seismograph and utilizing small charges of Primacord (1 to 4 lb) as the source of the shock wave picked up by the 12 geophones.

The conditions in the hills at both ends of the proposed swamp crossing were favorable for a rational interpretation of underground conditions. Most of the seismic work was concentrated in those areas. Four seismic profiles were made in the largest of the three Lomas Las Aisladas, one in Loma Tumara, and one in Middle Loma. Two seismic lines were run in the West Hills at the west end of the line. In general, these tests proved the availability of ample fill material for construction of the swamp crossing.

The conditions for seismic determinations in the swamp were definitely unfavorable because of the high energy absorption of the peat. Furthermore, the velocity in water, which saturates all of the strata in the swamp, may obscure the rigidity of the soil materials that the seismic work attempts to identify. Therefore, reliance in the swamp areas was placed mostly on the direct boring tests results.

## FIELD TESTS

Because of the difficulties in obtaining good samples for testing of the organic mat and of the softer silt, two types of field tests were utilized. First, the vane shear was employed in the softer organic and silt formations and, second, a loading test was made on the surface of the organic mat.

The vane shear test employed a cross-shaped metal vane attached to a small diameter probe rod. The vane shear was used in the soil borings in much the same manner as the standard penetration test. The vane was attached to drill rods and forced into the soil well below the bottom of the hole. It was rotated by means of a torque wrench. The torque required to initiate movement was recorded as a measure of the undisturbed shear strength of the soil. The vane was then rotated at least two revolutions, and the torque was measured again as an indication of the remolded strength of the soil. The vane produces shear on a cylindrical surface having the same diameter as the width of the vane. From the dimensions of the vane and the torque required to produce movement, the undisturbed shear strength of the soil was computed. These vane shear strengths were included in the soil boring records.

The load test was made with 143 fifty-gallon oil drums transported by helicopter and placed in a circular configuration in four layers pyramiding up above the swamp surface. The load was applied by filling the drums with water, one layer at a time. The

settlements were measured on the perimeter of the lowest layer and on the bottom of the second layer by level observations. These were made at intervals of one to five days after loading. A point of reference for bench mark was established using a 1-in. galvanized pipe forced approximately 28 ft into the swamp far enough from the load test that there should be no influence of load test settlement.

A major factor in this load test was the submergence effect of the oil drums that took place with the settlement. The settlement after the placing of the final load was nearly one meter. As a result, much of the lower tier of drums was submerged, which reduced their effective load substantially. Thus, the gross loading over the area of the test was 380 lb per square foot, but with four tiers of drums loaded, the net loading was only approximately 220 lb per square foot.

Later observations of this load test were needed to expand the time-settlement study, but these were precluded by a completely unexpected development. Observation during the height of the wet season was attempted by special helicopter flight in September, but it was discovered that the natives of the Darien had penetrated the "impenetrable" swamp by cutting a 2-mile canal for their canoes and had lifted all 143 drums.

## SAMPLES

Four types of samples were recovered from the field operations: (a) undisturbed Shelby tube samples obtained by use of the light tripod equipment in the swamp; (b) jar samples recovered from the barrel of the split tube used in performing the standard penetration tests; (c) rock cores and fragments recovered from operation of the Joy No. 7 core drill; and (d) bulk soil samples obtained from exposed strata and in the hills west of the Atrato River.

Those samples on which tests were to be performed were transported by airplane and automobile to the Solingral Laboratory in Medellin. It was necessary to have a courier transport each transmission of samples to insure against undesirable shock or damage and also to obtain release from internal customs inspections in Colombia, as such inspections, if performed on the undisturbed samples, would have destroyed their usefulness for laboratory work. Because emerald smuggling is prevalent in Colombia and the Atrato area is under hoof and mouth quarantine, we had some problems in satisfying inspection officials.

The testing program included moisture content, unit weight, void ratio, grain size analysis, time consolidation, Atterberg limits, and shear strength. For some selected samples, organic content and chloride content were determined. On a few of the rock samples, petrographic examinations, including thin sections and X-ray diffraction tests, were performed by the staff of the Law Engineering Testing Company or at the mineralogy laboratory of the Georgia Institute of Technology.

## SURVEYING AND MAPPING

Early in the planning, arrangements were made for photogrammetric mapping of the work area by the Aerial Surveys Branch of the Bureau of Public Roads, utilizing a photo plane of the Colombian Ministry of Public Works.

Targets and control towers had been prefabricated and lifted by helicopter to the swamp as the field work progressed. These control points were tied to the work line and to the established Inter-American Geodetic Survey controls by a crew of the IAGS, utilizing electrotape and theodolite equipment.

The survey data and photo negatives permitted the development of an uncontrolled photomosaic of the line and a planimetric map to accurate scale.

## SUMMARY

On the basis of all findings accumulated during these geophysical studies, the evaluation team concluded that construction of a highway across the Atrato River swamp is both feasible and practical. Three methods of construction are considered acceptable though the first is recommended as least costly and one that best fits the anticipated funding, timing, and service requirements although it entails some disadvantages.

1. Placement of fill material obtained from the Lomas Las Aisladas and the hills west of the Atrato River on the organic mat with consequent compression of the organic material and the soft subsurface layers.

2. Removal of organic material and the softer subsurface material and replacement with fill material obtained from the Lomas Las Aisladas.

3. Use of trestle construction across the entire swamp.

A complete report, including recommendations and design details has been furnished the Darien Subcommittee by the Bureau of Public Roads. The Darien Subcommittee will submit its final report in February, summarizing this study and the findings of all surveys made in the Darien over the past 10 years. This report, recognizing the Bureau of Public Roads findings, will recommend the short-route crossing of the Atrato swamps for bridging the gap between the American continents. Unquestionably the tremendous savings realized by adoption of the short route will encourage early consideration of funding for this project. The findings of the comprehensive geophysical studies described in this paper, which were accomplished at a total cost of approximately $100,000, could well generate a savings return in construction cost alone of over $100 million.