THE MERCURY TELESCOPE.

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At the request of the Editor of the Scientific American, the following account is furnished of the reflecting telescope of liquid mercury which I constructed at Easthampton, L. I., during the past summer. The idea of utilizing, in the construction of a reflecting telescope, the principle that the surface of a liquid in rotation assumes the form of a paraboloid, has been suggested from time to time for the past half a century, and as long ago as 1868 an instrument was constructed by Mr. R. C. Carrington in England, which was driven by a steam engine and was not a success, for reasons obvious to anyone who has attempted to use a mercury surface as a mirror, even when the fluid is at rest. So far as I have been able to find, no really serious attempt has ever been made to devise a method of setting a basin of mercury in rotation, without communicating to it jars which set up ripples on the surface of the fluid. I became interested in the problem more as a mechanical puzzle than anything else, but preliminary experiments with a poorly constructed mirror seven inches in diameter gave such promising results, that I determined to have constructed a larger instrument of the finest workmanship possible. Accordingly I ordered one 20 inches in diameter from Messrs. Warner & Swasey of Cleveland. Before preparing drawings for the large instrument, various experiments were made with the small model, in order to learn as much as possible about the sources of disturbance, and the best probable means of overcoming them. The fundamental idea, which made the solution of the difficulty seem possible, was to drive the basin by means of a rotating ring or collar, mounted on ball bearings, and carried on a support not in contact at any point with the mercury basin or its support. Various devices were tried for transmitting the power from the revolving ring to the mercury basin. The most promising appeared to be a magnetic clutch. A number of small horseshoe magnets were attached to the rotating ring, and a similar number to the basin, the poles of the opposed magnets being in very close proximity, without actually touching each other. When the outer ring of magnets was set in rotation, the inner magnets followed them, pulling the mercury basin around with them. It was found simpler, and almost as satisfactory, to transmit the power to the revolving basin by means of fine threads of India rubber, which transmitted little or no vibration from the driving ring.

The construction of the instrument is shown in Fig. 1. A plug of hardened steel, *A*, which was driven into the dish, rotated upon a second steel cylinder, *B*, which could be raised or lowered by means of the screw *C*, turned by a nut. The bearing surfaces of these two steel cylinders were ground flat and accurately perpendicular to the axis of rotation. Though the weight of the dish was carried upon the steel plug, there were in addition two conical bearing surfaces, which served to steady the basin during rotation. By lowering the dish the weight could be thrown wholly upon these surfaces, but in this position it could be turned only with difficulty. The best results were secured by raising the dish by an amount just sufficient to abolish this friction. The driving mechanism, or "rotor," a wooden pulley *F* mounted on ball bearings, was carried on a tripod *H*, supported independently of the rotating basin. The rubber threads were attached to the brackets *G*, six in number, and to the rim of the basin. As the instrument was originally designed, these brackets carried a steel hoop which surrounded the basin, the plan being to pack the space between with light tufts of cotton. It was found however, that jars were readily transmitted by the cotton. The instrument, speed pulleys, and electric motor are shown in Fig. 2.

The circular, flat-bottomed basin is filled to a depth of half an inch with mercury, the surface of which assumes the form of a perfect concave paraboloid under the action of centrifugal force, when the dish is rotated with a uniform velocity. The focal length of the concave mirror thus formed depends upon the speed of rotation, one turn in five seconds giving us a focus of 15 feet. As the speed increases, the focus shortens very rapidly, dropping to about three feet at a speed of one revolution in three seconds. The mercury telescope thus possesses the very remarkable property of having a focal length which can be varied at will.

It requires fully two minutes from the moment at which the dish is set in rotation for the fluid to attain the same velocity. The mercury begins to spin first along the rim of the basin, the motion being gradually transmitted toward the center. As we stand beside the dish and watch the reflection of the room in the surface of the liquid, the effect is quite startling. The room appears to expand in a most remarkable manner,

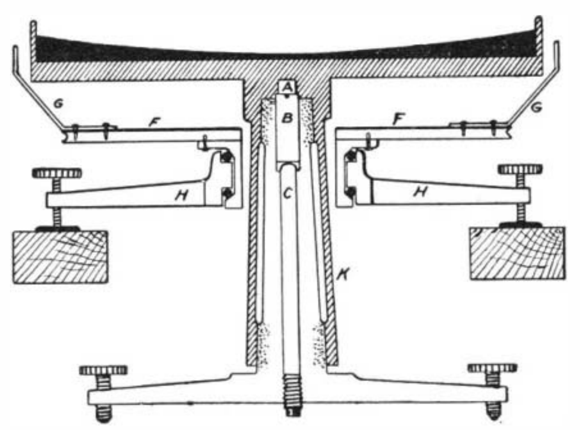

Fig. 1.—Construction of the instrument.

the ceiling retreating to a great height, and the walls moving outward. The smoothness of the mercury surface, and the freedom from ripples, is shown by the photograph, Fig. 3, of the real image in space formed by the concave surface. This image is inverted in reality, and it must be remembered that reflection in a flat surface (a pool of water, for example) would give us an image which is upside down, and not rightside up, as in the present case.

The mirror was mounted at the bottom of a cement pit 15 feet deep and 30 inches in diameter, with a foundation of granite blocks and cement 5 feet in thickness. At a distance of 6 feet from the pit a second shaft was sunk, and a tunnel cut through at the bottom. The observatory is shown in Fig. 2, the mouth of the pit being visible just inside the door. The tripod which carried the "rotor" was supported on a Y beam, imbedded in a cement pier at the bottom of the entrance shaft. The belt from the speed pulley passed under the floor of the tunnel, and was therefore not in the way when making adjustments of the mirror. It was found that everything depended upon getting the basin exactly level, which could be done only by watching the image of a Nernst lamp formed by the mirror when in rotation. The finer adjustments had to be made by observing the image of a star, which develops a "coma" if the instrument is not in perfect adjustment. It was found that the only outstanding disturbance was a system of long waves of very small amplitude, due to periodic variations in the velocity of rotation. Jars from the motor or from the grinding of rough bearing surfaces produce ripples of very short wave length, and these appeared to be completely eliminated. The periodic fluctuations in the velocity caused the focal length to vary slightly, the star images moving up and down rhythmically. This variation in the velocity was found to be due to the fact that the friction was not quite uniform, the force necessary to turn the dish being slightly greater in some positions than in others. At these points the basin lagged a little behind the rotor, the elastic threads stretching. On passing the point, the increased tension of the threads produced an acceleration, and the dish caught up again with the rotor. The source of the trouble has been located, and the instrument is now in the hands of the builders undergoing alterations.

Upon the whole, the definition was surprisingly good, when one considers the difficulties, much better in fact than I had ever dared to hope for. Readers of the Scientific American, who are interested in the subject, will find a fuller description of the sources of trouble and the methods of obviating them, in the Astrophysical Journal for March. The star images are formed a little above the mouth of the pit, where they can be examined with an eyepiece. By mounting a photographic plate in the focus, star trails can be obtained, which tell the whole story of the outstanding trouble. Instead of obtaining a narrow black line upon the plate, we find a series of black dots, each one about the size of a small pinhole. Between the dots the image broadens out to a diameter of about a millimeter. This is due to the periodic change of focus previously referred to, which trouble I hope to obviate.

The mercury telescope has the disadvantage that it can only be used for viewing objects near the zenith. With small instruments we can of course employ an auxiliary mirror, and view objects situated in any part of the sky, but with a large telescope this would be out of the question. Even with this limitation, interesting photographs of planetary details might be obtained, if it should prove feasible to build a reflector in a southern latitude, with a diameter of 10 or 20 feet. Very short exposures could be used. Probably 1/10 of a second would be sufficient, for the mirror is absolutely achromatic, and the ultra-violet rays could be utilized as well as the visible. Prof. Todd's photographs of Mars were taken with exposures of one-half a second, with a color screen which absorbed the larger part of the spectrum. It will be time enough to consider the advisability of building a large instrument, after the small one has been brought to a state of perfection.

Should it turn out in the end that complete elimination of the ripples is impossible, I feel very confident that they can be damped out by covering the mercury surface with some viscous transparent fluid. Experiments made last summer with oil showed this to be feasible, and more recently I have tried glycerine, which exerts a most astonishing effect. If we place a dish of mercury where it is violently agitated by jars, and cover the surface with glycerine, the waves disappear almost entirely. This may be of use in the case of artificial horizons.

The two most interesting objects which pass across the zenith at the latitude of Easthampton during the summer months, are the great cluster in Hercules and the Andromeda nebula. I have already had some splendid views of the great nebula, almost as satisfactory as with a large refracting telescope, since definition was not of so much importance. It can be seen to good advantage without any eyepiece, by merely looking down into the pit, where we see the oval phosphor-

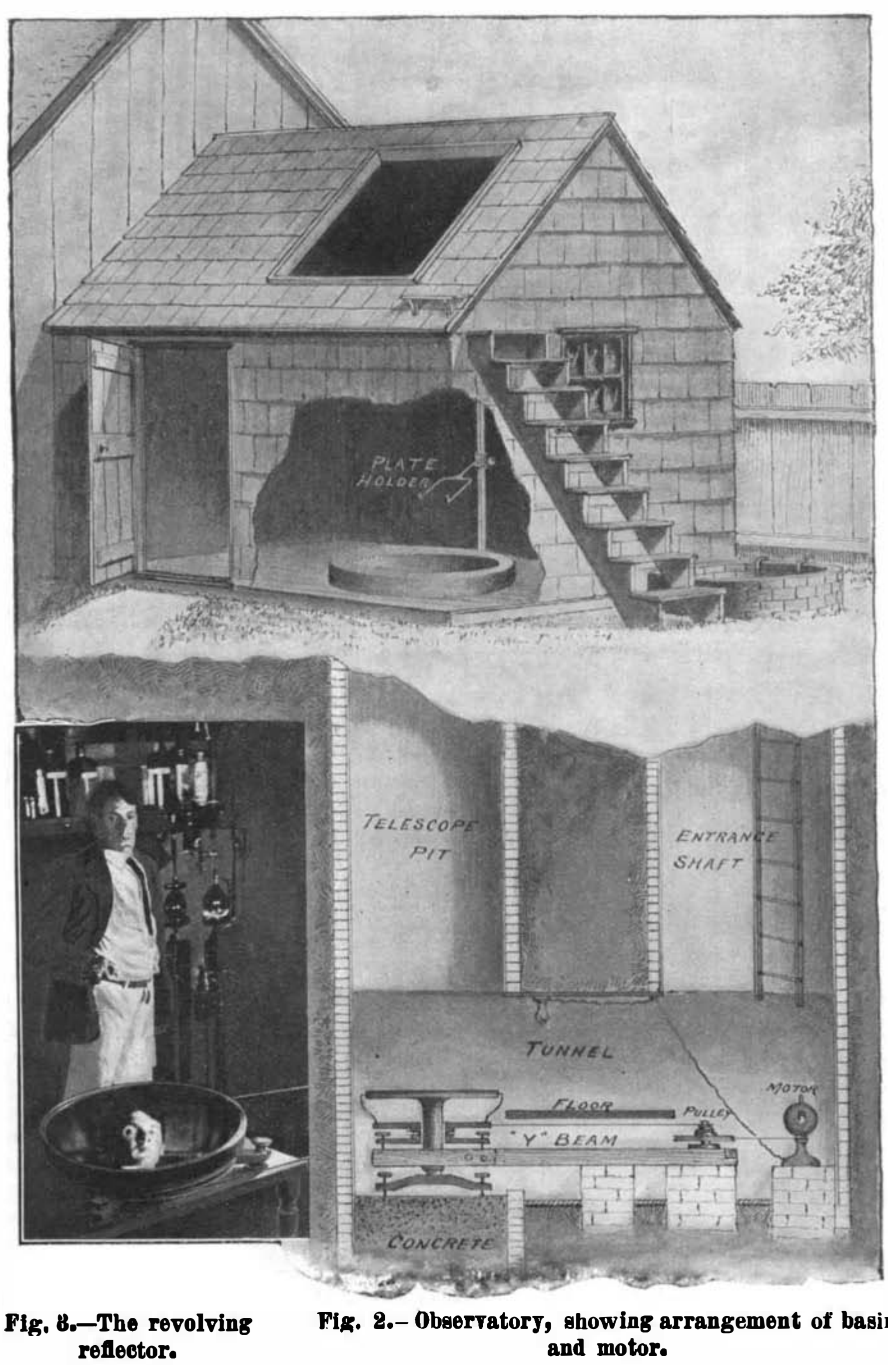

Fig. 3.—The revolving reflector.

Fig. 2.—Observatory, showing arrangement of basin and motor.

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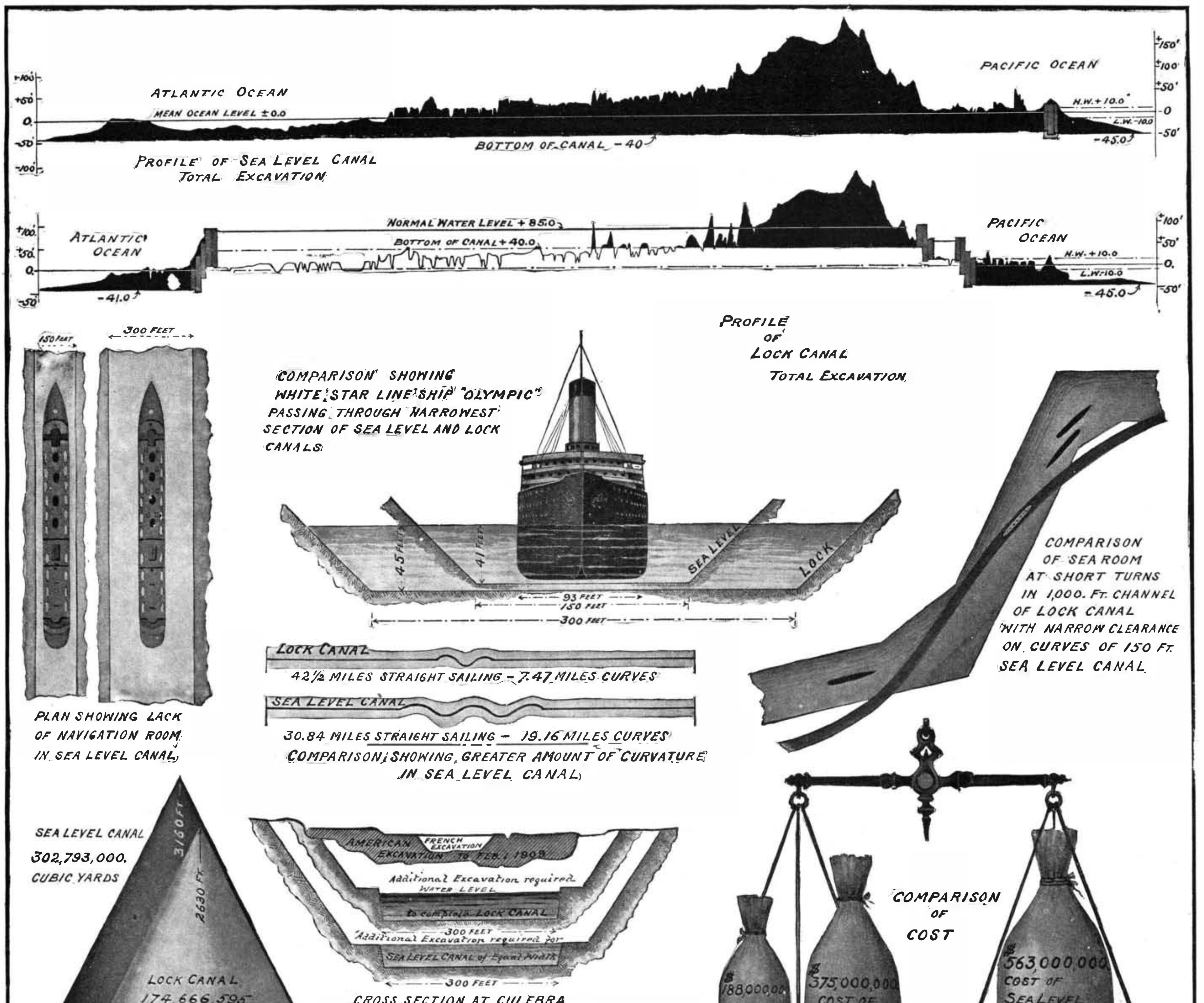
escent yellowish-green cloud floating in space. I am tempted in closing to tell of the remark made to me by one of the older inhabitants of Easthampton, who had paid my laboratory a visit. The Milky Way happened to be overhead, and the mouth of the pit, which was formerly an old well in a shed adjoining the barn, was filled with hundreds of star images. "What *are* they all, anyway?" he asked. "Suns like ours, only bigger," I replied. "You don't say so," he answered. "And have they earths and things going round 'em, and are they all inhabited?" "Very likely," said I; "some people think so." He scratched his head, and then turned to me with a restful smile and said, "Well, do you know, I dunno as it makes so *much* difference after all whether Taft or Bryan is elected."

My summer home at Easthampton was formerly an old farmhouse dating back to the reign of George the Fourth. On the door of the "observatory" we discovered a penciled memorandum "Heifer calf, born May 12"; under which my brother-in-law has inscribed, "Mercury telescope July 2."

Several cities in which household refuse is disposed of by incineration, have utilized the heat evolved by the combustion in the production of power for electric lighting and other purposes. Chicago has improved on this plan by making its sewage serve, indirectly, as a source of power. The Chicago drainage canal, which connects Lake Michigan with the Illinois River, a tributary of the Mississippi, and which was constructed for the purpose of carrying the sewage of the city away from the lake and furnishing an ample flow of water for this purpose, is traversed by a swift current. This current is now utilized in driving generators which supply part of the electric lighting service.



DIAGRAMMATIC COMPARISON SHOWING SUPERIORITY OF LOCK CANAL TO ONE AT SEA LEVEL.

SUPERIORITY OF LOCK TO SEA-LEVEL CANAL.

The reasons which have led the government to decide upon the construction of a lock rather than a sea-level canal are simple, clear, and convincing. This will be evident from a study of the comparative diagrams shown in the illustrations which accompany this article, in which the physical characteristics of the two types of canal, the quantities, costs, convenience of operation, etc., are shown side by side. The lock canal has been chosen, first, because it can be built more easily, more quickly, and in less time; secondly, because when it is built, it will be a much better canal to operate, the ships being able to pass through it with less risk and in considerably less time.

I. THE LOCK CANAL IS EASIER, QUICKER, AND CHEAPER TO BUILD.

1. Control of the Chagres River.—The key to the canal problem is the control of the turbulent Chagres River. The greater part of the canal lies along the course of the Chagres, which meets the canal at about its mid-length, and then turns to the right on its way to the Atlantic Ocean. In the dry season the river is a sluggish stream; but during the tropical rainstorms it rises with great rapidity, and may quickly be transformed into a vast turbulent torrent, flowing at the rate of over 65,000 cubic feet a second. These mighty waters must be checked, held in reserve, and gradually released; otherwise they would flood the canal, damage its works, and render it, for a long period of time, unnavigable. To control these floods, the sea-level plan calls for the construction of a $6,000,000 masonry dam across the Chagres Valley, above the point where the river reaches the canal, which, in times of flood, will be subjected to a pressure, due to a depth at the dam, of 170 feet of water. From above this dam the waters will be gradually discharged through sluice gates into the canal. In the lock canal plan the floods of the Chagres are received into a vast artificial lake, 160 square miles in area, which will cover the greater part of the route of the canal across the Isthmus. On the Atlantic side, the waters will be impounded by a dam at Gatun, and on the Pacific side by a dam at Pedro Miguel. This lake will take the place of about 25 miles of the narrow sea-level canal, and, for 20 miles of its distance, it will offer unobstructed deep-water sailing, in which the channel will be from 800 to 1,000 feet wide. The surplus waters will be wasted through sluice gates, built in solid ground at the center of the Gatun dam. Because of the great area and volume of the lake, the heaviest floods of the Chagres will make comparatively little difference in the water level. It will thus be seen that, while the sea-level plan calls for a $6,000,000 dam exterior to the canal for the control of the Chagres, the lock canal plan makes the Chagres subservient to the canal by forming it into a huge navigable lake; saves an enormous amount of excavation; and for 20 miles of distance secures a broad navigable channel in place of one only 150 feet in width.

2. The Lock Canal Requires Less Excavation.—A comparison of the longitudinal profiles and cross sections gives an impressive idea of the vast amount of extra excavation necessary, if the canal be dug down to sea level. The total amount of excavation for the completed lock canal will be 174,666,595 cubic yards. For a sea-level canal the total amount will be 302,793,000 cubic yards. Moreover, when the two are completed, the least width of the sea-level canal will be just one-half of the least width of the lock canal, and its average width only 218 feet, as against 650 feet; so that it may be said that nearly twice the work will have to be done for only one-third the