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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE OPERATION OF THE FACE CAISSON FOR INSPECTION AND MAINTENANCE OF THE SUBMERGED PORTION OF THE SPILLWAY FACE--GRAND COULEE DAM--COLUMBIA BASIN PROJECT, WASHINGTON

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Subject: Hydraulic model studies of the operation of the face caisson for inspection and maintenance of the submerged portion of the spillway face--Grand Coulee Dam--Columbia Basin Project, Washington

Reference: A summary of the operating procedure for the mooring, sinking, and refloating the caisson, based on the findings given in this report, is given in Hydraulic Report No. 264.

PURPOSE OF STUDY

The spillway face caisson for Grand Coulee Dam was designed to make accessible for inspection and repair that portion of the spillway face which is normally submerged by tail water. A major problem was to determine a satisfactory and safe operating procedure to place, moor, sink, unwater and refloat the caisson. The problem was complicated by the large size of the caisson and a 10-foot variation in tail water elevation. Part of the solution to this problem was obtained by hydraulic model tests. This report presents a description of these tests, the test results, the conclusions reached, and recommendations.

CONCLUSIONS

1. The best procedure for mooring, sinking, and refloating the caisson on the spillway face is given in the section of this report describing the Operation of the Spillway Face Caisson, page 8.

2. If the mooring procedure as given in Specifications No. 1108 were followed, the caisson could be tilted to reach the mooring post only if the water surface is above elevation 936 approximately (Figure 17). Also sinking the caisson onto the spillway would necessitate the addition and removal of water in the ballast tanks in a manner that might become involved and time consuming.

3. The lower ballast tank must be divided into three compartments. If the lower tank is a single compartment, a severe sidewise list will occur when the angle of tilt is more than 45°.

4. When the caisson is floating, the tilt angle depends primarily on the amount of water in the lower ballast tank, and when the tilt angle is greater than 10°, the addition of a small quantity of water to this tank will cause a comparatively large increase of the tilt angle (Figure 16).

5. The height the front end of the caisson lifts out of the water when tilted depends on the weight of the caisson, and is greatest when the upper ballast tank is empty (Figure 15).

6. The 1:20 model caisson was heavier than the prototype design; but by assuming that the model's ballast tanks were partly filled with water, the relation of tilt to the amount of water in the lower tank and the height the caisson front end lifts out of the water compare reasonably well with the design curves (Figures 14, 15, and 17).

7. The caisson can be tilted by placing water in either the upper or lower ballast tanks, and to a limited extent by applying force to the lateral control lines. However, using the lateral control lines to tilt the caisson is not advocated.

8. The dual wheels of the caisson should be held against the spillway face during mooring with a minimum force of 10,000 pounds (Figure 8) which is accomplished by following the procedure referred to in Conclusion No. 1. This procedure requires the caisson to be pulled up to the mooring post by a cable at the top of the dam or by similar means. Mooring the caisson by the other procedures tested will allow the caisson wheels to lift off the spillway face, and the caisson will become unstable laterally.

9. With the lower ballast tank about 78 percent full, the force on the mooring post is independent of the amount of water in the upper ballast tank and the riverwater surface elevation provided that the tilt angle does not exceed the slope of the spillway (Figure 8).

10. The force on the mooring post will become excessive if the lower tank is filled less than 65 percent, and with high riverwater elevations, this force will become zero with the lower tank 80 to 84 percent full (Figure 8).

11. The force required to pull the caisson to the mooring post and the force of the wheels against the spillway are nearly constant throughout the pulling operation. Further, the pulling forces and wheel loads are nearly equal to the force on the mooring post after the caisson is moored (Figures 7 and 8). This equality holds only when the angle of tilt does not become so great to cause the caisson lower end to drag against the spillway.

12. After the caisson is moored, but before it is sunk against the spillway, the tilt angle depends upon the water in the ballast tanks and the tail water elevation (Figure 8).

13. The caisson rubber seal is likely to be damaged if the lower end of the caisson strikes the spillway first, which drags the seal. This damage can be avoided by mooring the caisson with the wheels kept firmly against the spillway.

14. The model sealed easily against the spillway with no indication of leakage, but troubles may arise in the prototype which cannot be studied by the model. If sealing trouble is experienced, the operator should be careful when filling the ballast tanks for the purpose of exerting pressure against the spillway, for this procedure may overload the mooring post (Figures 8 and 9).

15. The caisson may be unsealed, released, and refloated in the reverse of the mooring and sinking procedure as given in the Operation of the Spillway Face Caisson section of this report, page 8, or the caisson may be released and then allowed to glide downward into the water. This latter procedure appeared satisfactory with the model when the lower ballast tank was approximately 75 percent full; however, it is questionable for the prototype, for when the caisson breaks the surface, surges and boils may occur which may be dangerous to personnel.

RECOMMENDATIONS

1. Before the prototype caisson is moored, determine by field tests the relation of tilt angle to the amount of water in the upper and lower ballast tanks, and if necessary, correct Figures 5, 6, and 16.

2. Use the operating procedure for mooring, sinking, and refloating the caisson that is given on pages 8 and 9 and Figures 5, 6, and 9 of this report or Hydraulic Laboratory Report No. 264.

3. Do not use the lateral control lines for tilting the caisson.

4. If the mooring post is used as an anchor in the mooring operation, do not pull the caisson up the spillway too fast as the pulling force on the mooring post may increase as much as 100 percent, and after the caisson is moored, it will rock about the wheels and cause considerable fluctuation of force on the mooring post.

INTRODUCTION

General Features of Grand Coulee Dam

The spillway for passing surplus flow from the reservoir to the river downstream has a gross length of 1,650 feet (Figure 1.) The spillway flow is controlled by 11 hydraulically operated drum gates, 28 feet high by 135 feet long, separated by piers supporting a roadway across the dam. Two training walls on the downstream face of the dam confine the spillway flow to a roller bucket stilling pool at the toe of the dam. The difference in elevation from the reservoir water surface to the tail water will vary from 350 feet for low discharges to 280 feet for the maximum discharge of 1,000,000 cfs. The sixty 102-inch diameter river outlets arranged in three tiers, each differing in elevation by 100 feet, pass through the right two-thirds of the spillway section. Each tier consists of 20 outlets grouped in pairs and located directly above or below those of the other tiers. All emerge from the downstream face and discharge down the spillway face into the stilling pool. The two powerhouses, one at each end of the spillway at the base of the dam have an ultimate capacity of 945,000 kw each. They discharge their flow from the turbines through draft tubes into tailraces excavated into the riverbanks, where it passes into the main river channel downstream from the spillway stilling pool.

During the period of construction of the dam, it was necessary to release the flow of the river over the spillway section in an unsymmetrical manner, and damage to the concrete surfaces of the bucket resulted by an upstream movement of boulders from the riverbed. Over a period of time damage has also occurred to the submerged portion of the spillway face due to erosion and spalls at the construction joints. Because the bucket and this portion of the spillway face are submerged by tail water they are not accessible by usual means (Figure 2). Therefore, two access caissons were designed to permit inspection and repair--one for the bucket section and the other for the below water portion of the spillway face. This report is concerned with the hydraulic model studies of the operation of the caisson for the spillway face. All studies of the operation of the caisson for the bucket are described in the Laboratory Report Hyd. 174, "Hydraulic Model Studies Pertaining to the Repair, Maintenance and Protection of the Spillway Bucket and the Protection of the Tailrace Slopes and Downstream River Banks at Grand Coulee Dam," by J. W. Ball.

Description of Spillway Face Caisson

The face caisson is a box-like structure 58 feet long, 54 feet wide, and 9 feet high, Specifications No. 1108. It will be floated to the spillway, moored into position, tilted, and sealed to provide an access chamber for inspection and repair of the spillway face between elevations 901.0 and 945.0 (Figure 2). The caisson is divided into two sections (Figure 3). The working space next to the spillway is a single compartment 4 feet high. The space above, which is 5 feet high, contains structural beams and is divided into watertight compartments. Two of these compartments are ballast tanks, and are designated as the upper and lower tanks according to their respective location when the caisson is tilted into position against the spillway (see Section A-A of Figure 3). The upper ballast tank may be filled with water to assist in sinking the caisson while the lower tank will be filled with water mainly to tilt the caisson. The lower tank may also be used to trim the caisson (maintain an even keel) for it is divided into three compartments which may be filled individually to counteract any tendency to list. A trim tank located above the upper ballast tank at its right side may be filled with sufficient water to balance the weight of the pumps, piping and equipment on the top and left side of the caisson.

The caisson is built of steel girders, plates, and webbing joined by bolts, rivets, and welds to make the single unit as shown in Figure 3. Timber bumpers are added to the sides for protection during maneuvering in the river channel below the dam. Two dual wheels at the front permit the structure to roll up or down the face of the spillway luring operation. An A-frame tongue is located at the front or upper end which will be attached to a mooring post anchored on the spillway face at elevation 954.35 to hold the caisson in position during the tilting and placing operations. The rigging arrangement to pull this A-frame to the mooring post is shown in Figure 4. A peaking post or hoist frame is located above the A-frame and is connected to the A-frame by peaking lines. Pull-in lines may also be connected from the hoist frame to the mooring post. To align the A-frame to the mooring post, the A-frame contains a guide shoe, and the mooring post a connecting guide which steers the guide shoe to the post where it may be pinned into position.

Other rigging includes the lateral control lines as shown in Figure 4, and such lines as may be necessary to attach to tugs or barges during maneuvering. The equipment on the caisson consists of the hoist machinery for the mooring operation, and pumps to fill or empty the ballast tanks and to unwater the work chamber. A specially designed rubber seal extends around the bottom of the work chamber to seal it on the spillway face. A valve-operating platform on the top side provides walking and working space for the operators, and also furnishes support for the hoisting machinery.

Whenever the operator begins to tilt and moor the caisson he must know the amount of water he has placed in the tanks. To determine these amounts, the caisson is provided with liquid level gages on the operating platform. The caisson must also be provided with an instrument for measuring the degree of tilt of the caisson. As shown by the sketches of Figures 5 and 6, the liquid level gages measure the head, H, above the lower corner of the rectangular-shaped ballast tanks. To use the gages, air is pumped slowly into the line. The pressure reading on the dial will indicate the head when all water is forced from the line.

It is apparent that this head will depend not only upon the quantity of water in the tank, but also upon the angle of tilt of the caisson. Therefore two sets of curves are presented (Figures 5 and 6) with OC, the tilt angle as the ordinate, H, the head above the lower corner of the tank as the abscissa, and the various curves representing the different amounts of water in the tanks. Thus, by measuring the tilt angle and the head, the amount of water in the ballast tanks may be found. It is to be noted that two curves are provided for the lower tank. Case 1 is where all compartments are filled uniformly and Case 2 is where the side compartments are filled 95 percent first, and the center compartment is then filled. The percentage curves for Case 2 refer to the total percent of water in the lower tank and not to the percent of the water in the center compartment. It was believed best to fill the side compartments only 95 percent to give a small amount of leeway to permit the addition or subtraction of some ballast for balancing or trimming the caisson.

OPERATION OF THE SPILLWAY FACE CAISSON

Initial Operating Procedure, Specifications No. 1108

In general, procedure for operating the caisson was developed by the design department and included in the Specifications No. 1108 (see Figure 7). It was intended to float the caisson to the dam with tugs or barges to the approximate position in front of the spillway, and then attach the pulling-in lines and lateral control lines (Figure 7, Instructions 1 and 2). The next step was to tilt the caisson to enable the guide shoe on the A-frame to contact the connecting guide on the mooring post. The caisson would then be pulled to the spillway and tilted upwards until the A-frame reached the mooring post where it could be secured by a pin (Figure 7, Instructions 3, 4, 5, and 6). Once attached to the mooring post, the caisson would be sunk and sealed against the spillway (Instructions 7 and 8). The tires of the two wheels would then be deflated to prevent overloading them, and the working space unwatered. As a final step it was planned to drain the air chambers of leakage and to release the A-frame from the mooring post (Instructions 9, 10, 11, and 12).

Upon completion of the necessary repair work on the spillway face unwatered by the caisson, the working space would be refilled, the seal broken, and the caisson refloated to a horizontal position to be moved on to the next repair section or to be returned to its dock downstream.

It was realized that the operating instructions and charts of Figure 7 were general and would not necessarily apply to all of the conditions under which the caisson might be used. For instance, the river water surface elevation could vary as much as 10 feet, and it was possible that the mooring operation with the water surface at elevation 945.0 would be quite different from the operation with the water surface at elevation 935.0. It was also possible that a different sequence of maneuvers might be used to advantage during the placing operation. Even more speculative was the unsealing operations. Should the caisson be refloated in exactly the same manner as it was sunk, or would another procedure be more advantageous. To determine how the caisson would act as it was sunk and sealed against the spillway and then refloated, and to obtain a comprehensive schedule for the operations, a 1:20 scale model was built and studied in the Hydraulic Laboratory.

Model Test of the Initial Operating Procedure

The general steps as outlined in Specifications No. 1108 for mooring and sinking the caisson were given in the previous section and in Figure 7 of this report. Preliminary model studies of these operations showed that it was essential that the proper amounts of water be placed in the ballast tanks for the various river water surface elevations to avoid overloading the A-frame and mooring post, and to avoid damaging the seals during the sinking and sealing operation. These amounts of water were determined and are presented in Figure 8, but because these curves are rather awkward for the operator's use, the pertinent data were rearranged and plotted in Figures 9, A and B.

The maximum quantity of water which may be placed in the upper tank for the mooring operation for the range of river water elevation to be encountered may be obtained from the dashed curve (a) in Figure 9A. Water is then placed in the lower tank to the amount shown by the upper curve (a) in Figure 9B to tilt the caisson enough to allow the guide shoe on the A-frame to reach the connecting guide on the mooring post. After the A-frame is secured to the mooring post, water must then be removed from the lower tank to the amount shown by the lower curve (b) of Figure 9B. The removal of water from the lower ballast tank is necessary so that the caisson will not tilt beyond the slope of the dam and allow the lower seals to drag when the caisson is sunk to the spillway face. The final step is to fill the upper tank to some value between the maximum and minimum amounts, curves (b) and (c) (Figure 9A) to seat the caisson against the spillway face.

It is possible, due to certain corrections which were made to obtain better similitude between the model and prototype and to the uncertainties involved in the weight estimate of the prototype caisson, that the percentages of water to be placed in the ballast tanks may vary slightly from those given in Figures 9A and 9B. It is therefore recommended that field tests be made to determine the prototype relationship of angle of tilt to quantity of water in the ballast tanks and that the percentage scales on Figures 5, 6, 9A, 9B, and 16 be shifted if necessary.

Revised Procedure, Based on Laboratory Tests

The revised procedure differs from that given in Specifications No. 1108, principally in that the caisson is pulled up the face of the spillway or lifted to the mooring post with a definite force instead of being trimmed and floated to it. The reason for this procedure lies in the fact that there is poor lateral stability of the upper end of the caisson when sidewise currents exist and when the wheels are not in firm contact with the spillway face. It was found by model tests that when the caisson was pulled up the face of the spillway to the mooring post, there was a load on the wheels approximately equal to the pulling force. Therefore by pulling the caisson to the post by a relatively large force, the wheels are held firmly against the spillway and good stability is insured. It should also be pointed out that at water surface elevation less than about 936.0, the specification procedure for mooring the caisson will not apply because the front end cannot be floated high enough to reach the mooring post. Therefore, it will be necessary to pull the caisson up the spillway face or lift it to the post regardless of the procedure used.

As in the initial procedure, the upper tank must not be filled more than indicated by the dashed curve (a) in Figure 9A for the mooring operation. Then the lower tank is filled to the value shown by the bottom curve (b) in Figure 9B. Next a cable is used to pull or lift the caisson up to the mooring post where the A-frame is secured. Finally the upper tank is filled to an amount between the maximum and minimum curves (b) and (c) of Figure 9A to seat the caisson to the spillway face. This procedure is explained in detail in Hyd. Report No. 264 on the "Operating Instructions for Mooring, Sinking, and Refloating the Grand Coulee Face Caisson." The most important advantage of this procedure is that good stability of the upper end of the caisson is insured because the wheels are always in firm contact with the dam. Another advantage of this mooring procedure is that the necessity for removing some of the water from the lower tank prior to sinking the caisson is eliminated.

DISCUSSION

Description of the 1:20 Model

The 1:20 scale model was made similar to the prototype design previously described in the Introduction section of this report (Figure 10). The model was of sheet metal construction. The pumping equipment was not included because it was unnecessary. To admit and remove water from the ballast tanks and work compartment, copper tubes led from the compartments to the workdeck at the front end of the caisson. The upper ends of these tubes were accessible with the caisson at any position, and a suction or water supply line could be easily connected to the tubes to remove or add water as needed. Likewise the hoist machinery on the model was considered unnecessary because the cables which connected the caisson to its mooring post could be easily operated from the mooring post itself and accomplish the desired results.

Preliminary Floating Tests

The model caisson was placed in the water initially to observe the manner in which it floated. With the ballast tanks empty, the freeboard was measured and it was found that the attitude was very nearly that anticipated for the prototype except that the rear left corner was slightly lower than the right. As water was placed in the lower ballast tank, the back end of the caisson submerged slowly on an even keel until it was tilted to an angle of approximately 10°. Then, as water was added in very small quantities the submergence increased rapidly until the angle of tilt became approximately 70°. As the caisson tilted, it appeared to rotate about a horizontal axis or pivot located at the front end near the water surface. When tilted more than 45°, the caisson developed a list, tipping sidewise to the left nearly 15°. Although the natural tendency was to tip to the left, if a small counterbalancing weight were added to the right side, the caisson could be made to tip in either direction. It was not stable and would not remain in an upright position, and the listing was apparently caused by a shifting of the water load in the lower ballast tank. To obtain an indication of the forces required to right the caisson, a line was attached to the front corner and pulled to level the caisson transversely. A force of approximately 11,200 pounds (1.4-pound model) was required.

Suggestions to prevent this list included holding the front wheels against the face of the spillway, using control lines, and dividing the lower ballast tank into three compartments to prevent shifting of the water load. The latter idea seemed most practical, and a study was made to determine the proper size of the compartments. It was desirable to have the compartments nearly the same size, but at the same time to have the outside compartments of such size that they could be filled before the caisson tilted appreciably. Thus it would be possible to control the tilting operation by filling the center compartment. To determine if this were feasible, the relation of tilt to the amount of water in the lower tank was studied. The caisson was first floated with all tanks empty, then known amounts of water were added to the single lower tank and the resulting angles of tilt measured. It was found that the lower tank could be filled 70 percent before the tilt would exceed 8°, and before the rate of tilt would increase greatly with additional amounts of water (Figure 11). Therefore, it was decided to make the center compartment 20 feet wide and the side compartments 17 feet 6 inches wide; for, with the side compartments filled, the angle of tilt would then be approximately 6-1/2°. This would provide ample safety against passing through the region of sudden change in tilt by the addition of small quantities during the filling of the center compartment.

Development of the Final Model Design

When the model was revised by separating the lower ballast tank into three compartments, refinements such as wheels, the hoist frame, timber bumpers, and seals were added (Figures 10, A, B). The pumping equipment and hoist machinery were not included since they were unnecessary. The first test was to float and tilt the caisson in a manner similar to that of the preliminary test. When the two outer compartments of the lower ballast tank were filled, the tilt was approximately 6-1/2°. As the middle compartment was filled slowly, the caisson settled on an even keel without listing laterally, and if tipped sidewise would right itself. With the three compartments of the lower ballast tank filled, the angle of tilt was approximately 80°, and when floating in this position, a small force or wave action would cause the caisson to bob up and down in a manner similar to a floating cork. It was attempted to overturn the caisson by rotating it through an angle of 90° but this could not be done without exerting an unreasonably large force. It was apparent that the caisson would operate satisfactorily in all respects without further revisions. Thus the model represented the final design.

Studies of the Mooring Operation

The model caisson is shown in various positions during the mooring operation in Figures 12 and 13. The importance of a study to ascertain a proper procedure for mooring became apparent in preliminary tests of this maneuver; for an improper amount of water in the ballast tanks would either cause the A-frame and mooring post to become overloaded, or would cause the A-frame to exert an upward thrust against the mooring post, lifting the wheels from the face of the spillway and creating an unstable condition.

Sufficient water was placed in the ballast tanks to permit the caisson to be tilted and attached to the mooring post by a small pull on the A-frame. The river water elevation was then changed. When the river water was raised, the A-frame pushed upward against the mooring post and the wheels lifted off the spillway, but when the river water was lowered the pull on the mooring post increased. It was estimated that the force caused by a change in elevation of 1 foot was 22,000 pounds, and it was apparent that should the river water elevation change during mooring operations, the amounts of water in the ballast tanks should be changed to meet the new conditions.

When the wheels were lifted off the spillway, the caisson was none too stable laterally, especially if sidewise currents existed. This condition was aggravated by the lateral control lines which would hold the lower end of the caisson in position while the upper end would be free to drift unless held by other means. It was possible to hold this upper end by the friction of the wheels against the spillway, or by the connecting guide on the mooring post. However, it was found that the connecting guide was none too efficient in this respect because the guide shoe on the A-frame would rotate permitting the caisson to move sidewise. The best method for insuring lateral stability was to hold the wheels firmly against the spillway throughout the entire mooring operation if this were possible. It was believed that the total wheel load force should be about 10,000 pounds.

The procedure outlined in Specifications No. 1108 for mooring the caisson when the water surface was above elevation 937.0 was then attempted. The caisson was floated into position in front of the spillway and given an initial tilt so the A-frame could reach the mooring post. When attached to the mooring post, water was placed in the upper ballast tank to lower the wheels against the spillway, but in doing so the angle of tilt increased rapidly and the lower edge of the caisson touched the face of the dam with a sliding motion. This was undesirable for such an incident in the prototype might damage the seals. The procedure was then modified by placing additional water in the lower ballast tank, but this not only caused the tilt angle to increase, but also caused the caisson to lift upward, pushing the wheels away from the spillway. A satisfactory procedure was worked out by (1) tilting the caisson so the A-frame could reach the mooring post; (2) removing some water from the lower ballast tank; (3) placing water in the upper ballast tank; and, if necessary, (4) again placing water in the lower ballast tank. The removal of water from the lower tank after the caisson was moored prevented the lower end of the caisson from touching the spillway, but it was found that if too much water was removed, the mooring post would become overloaded. It was apparent that further tests of a quantitative nature should be made to determine the amounts of water which should be removed or placed in the tanks.

In tilting the caisson against the spillway, it was found that the operation could be aided by applying a force to the lateral control lines, for when these lines were under tension there was a component of force pulling the lower end of the caisson toward the spillway. While this might be a useful maneuver in case of necessity, it is not recommended that it be relied upon. Accordingly, the mooring operations described in this report were made with negligible tension on the lateral control lines or just taut.

It appeared that the above procedure for mooring the caisson might become complicated in that several steps of filling and removing water from the ballast tanks might be necessary. Moreover, the wheels would not be held against the spillway during that part of the mooring operation where the guide shoe on the A-frame contacts the connecting guide and slides into position at the mooring post; and as previously explained, the caisson would be at the mercy of the lateral currents. Therefore a new mooring procedure was studied whereby the caisson would be pulled to the mooring post by means of a cable from above threaded through a block on the mooring post and attached to the A-frame. This cable could be supplied by the crane on the roadway at the top of the dam or by other convenient means. The idea of pulling the caisson to the mooring post originated when it was found that the force of the wheels against the spillway would be practically the same as the force on the cable during the pulling operation. The procedure tried on the model was as follows: (1) water was placed in the lower ballast tank to tilt the caisson sufficiently to reduce the pull to a desired limit, but not enough to tilt the caisson beyond the slope of the dam, (2) the caisson was pulled to the mooring post and secured, (3) water was then placed in the upper ballast tank to sink the caisson against the spillway without lifting the wheels off the spillway or causing the lower end of the caisson to strike the spillway first.

There appeared to be some advantages in each of the two procedures, but the second is preferred since it provides better control and stability of the caisson.

Sealing and Refloating the Caisson

Once the caisson was moored and sunk, the important operation of unwatering the work chamber would commence. No difficulty was experienced with the model during this operation, for the seals held tightly. Moreover, it was discovered that when a small amount of water was removed from the work chamber, the unbalanced pressures caused the caisson to be pushed tightly against the spillway, further aiding the sealing operation. The action should be the same in the prototype. However, if there are bad spalls in the surface of the spillway face under the seals, difficulties might be encountered in the unwatering operation. These are prototype problems. However, if trouble is encountered in the prototype, the operator must be careful in filling the ballast tanks to exert pressure against the spillway, for he may easily overload the mooring post.

The process of refloating the caisson was to place desired quantities of water in the ballast tanks for the existing river water elevation at the caisson location and to refill the work chamber. It was anticipated that the work chamber could be filled above the water surface in the tailrace to build up a force to break the seals loose, or it might be possible to supply this force by emptying the ballast tanks. No difficulty should be encountered unless the rubber seals of the prototype became stuck to the concrete on the spillway; although such a circumstance is not likely. The refloating operation was first performed with the ballast tanks empty and with the A-frame attached to the mooring post. As soon as the work chamber was filled, the caisson broke free and lunged upward against the mooring post pushing the wheels off the spillway. Then, as it leveled off, the wheels dropped against the spillway causing a severe jerk on the mooring post. The forces on the mooring post were far in excess of the designed load limit of 65,000 pounds. It was thus apparent that such a procedure for refloating the caisson should never be attempted.

The next test was to refloat the caisson by pumping the ballast tanks empty but with the A-frame disconnected. In this case, the caisson lunged upward, but with the wheels rolling on the spillway. The next movement was downward with the lower end of the caisson lifting away from the spillway and the wheels rolling against it. This was followed by another upward and downward surge until the caisson leveled off. As the caisson leveled off, it moved away from the spillway. As far as could be seen, this method of refloating would be satisfactory, but it is not to be recommended for the personnel aboard would be subjected to a rough ride, and it is doubtful if any control could be exerted by the pulling-in and lateral control lines.

This refloating operation was repeated, but with the lower ballast tanks about 75 percent full. In this case the wheels rolled down the spillway and at the same time the lower end of the caisson rose to the surface. As the wheels submerged and as the caisson leveled, the momentum forced it away from the spillway. The action in this case was not nearly as severe as in the former trials, and it was concluded that the caisson could be safely refloated by releasing it if the lower ballast tanks were about 75 percent full. However, this type of release would mean that the pulling-in and lateral control lines could not be attached for the sudden movements might break the lines. A test was made by tilting the caisson sidewise as it was released from the spillway to determine if it would refloat properly if it were listing as it rolled down the spillway. Aside from being pushed away from the spillway in a different direction than formerly, no adverse effects could be observed.

The safest refloating procedure found was to reverse, step by step, the procedure for mooring and sealing. However, it would be necessary to adjust the water in the ballast tanks to compensate for changes in river water elevation; for instance, if the caisson were moored with the river water at elevation 937.0 and refloated when the river water was at elevation 943.0, the quantities of water in the ballast tanks would have to be changed.

Similarity Between Model and Prototype Weights

It was desirable to determine the similarity of the model to the prototype with respect to weight, location of the center of gravity, the floating positions, and the amounts of water which could be placed in the ballast tanks. Then, it would be possible to make adjustments and corrections to the model to make it as similar to the prototype as possible. All water was removed from the ballast tanks, and the caisson was weighed, balanced to find the center of gravity, and floated to determine the freeboard at each end. These results, compared with the design values in Figure 14, indicated that the model was relatively heavier than the prototype, that its center of gravity was closer to the front, and that the front of the model floated deeper in the water. The amount of water each compartment of the lower ballast tank and the upper ballast tank could contain was measured and found to compare well with that of the prototype estimate.

It was believed expedient to make a correction to account for the excess weight of the model. To do this without difficult revisions, the excess weight was accounted for by assuming that the model was correct, but that a certain amount of water was contained in the upper and lower ballast tanks. To have a model of the same weight as the prototype and with the same location of the center of gravity, the equivalent excess weight of 33,000 pounds was divided into two parts, 20,800 pounds for the upper ballast tank, and 12,200 pounds for the lower tank. Since the capacity of the upper tank was 238,000 pounds, it must be assumed that it was initially 8.73 percent full; likewise, since the capacity of the lower tank was 300,000 pounds, it must be assumed that it was initially 4.07 percent full.

The estimated weight of the prototype caisson of 507,000 pounds was uncertain, and may have not included some features such as hoisting machinery on the platform, nor the additional material required to divide the lower ballast tank into three compartments. Finally, if the trim tank above the upper ballast tank at its right side were filled, the actual weight could be considerably more than that of the estimated 507,000 pounds.

It was believed desirable to add an additional 9,000 pounds to account for the possible loads which were not considered in the original estimate of the prototype weight; for example, the material required to divide the lower ballast tank into three compartments. Therefore, it could be assumed that the ballast tanks of the model were initially filled with the equivalent 24,000 pounds of water, with the upper ballast tank 6.36 percent full and the lower tank 2.95 percent full. However, the results of the model tests were not analyzed upon this basis, but upon the estimated 507,000 pounds. It was believed that if an error were made in the weight estimate, it would not be significant because the recommended quantities in the ballast tanks would not differ more than 2.4 percent for the upper tank and 1.1 percent for the lower tank.

Change in Angle of Tilt and Elevation of Front End for Various Amounts of Water in the Lower Ballast Tanks

To study the tilting operation quantitatively, the side compartments of the lower ballast tank were filled and then the center compartment filled with measured amounts of water. The upper ballast tank was empty or equivalent to 8.73 percent full with the caisson weight correction applied. The relation of tilt angle to the total percent of water in the three compartments of the lower ballast tank was compared with measured values of the original model, and found to be similar, indicating that the increased weight of the final model had only a minor effect upon the angle of tilt (Figure 11). The ballast tanks were then emptied and the test repeated. However, this time the three compartments of the tank were filled uniformly maintaining the same depth in each. The results were nearly identical with the former test and it was concluded that either method may be used.

The relation of tilt angle to the percent of water in the lower ballast tank would be difficult to measure directly when the prototype caisson is in operation. Either the curves of Figures 6 and 8 or the curve in Figure 7 would have to be used. The curve of the specification drawing "Ballast Required to Tilt the Caisson" is shown enlarged in Figure 15, and model data are included for purposes of comparison. Considering the fact that the model was heavier than the prototype, this comparison is fairly close.

Another comparison, by use of the L curve of Figure 15, shows the height L the front end of the caisson will lift out of the water for a given angle of tilt. It is noted that the model curve does not agree with the prototype estimate, although similar in shape.

This is to be expected since the value of L depends upon the weight and submergence of the caisson. Since the model is comparatively heavier, the model curve should indicate smaller values of L, as it does, and it is possible to correlate these model and prototype curves for any given angle of tilt by computing the force which sinks the model deeper. This force was computed to be approximately 29,500 pounds, and thus the actual comparison of total weights will be 540,000-29,500 or 510,500 pounds, while the prototype estimate is 507,000 pounds.

Change in Angle of Tilt for Various Amounts of Water in Both Ballast Tanks

The relation of the angle of tilt while floating to the amount of water in the lower ballast tank had been studied previously (Figure 11). In that test corrections had been made to account for the heavier model by assuming that the upper ballast tank was initially 8.73 percent full and the lower ballast tank was 4.07 percent full. These corrections had been based upon the weight of the dry caisson. When the tests were repeated to study further the relation of tilt with respect to the various amounts of water, not only in the lower ballast tank, but also in the upper, it was found that the weight of the model caisson had been increased several pounds evidently due to water in the tanks which could not be removed. By assuming this increase to be divided equally between the upper and lower tanks, it was estimated that the lower tank would be initially 7.49 percent full and the upper tank 13.03 percent full.

When the relation of tilt angle to percent of water in the lower tank, considering the upper tank to be empty, was compared with the former test it was found that the two curves did not agree (Figure 16). However, the actual amount of water placed in the lower ballast tank to tilt the caisson to a given angle was nearly the same in both tests and the two curves differed only by the amount of their lower tank corrections, 4.07 and 7.49 percent full. This was to be expected since the angle of tilt depends primarily on the amount of water in the lower ballast tank. It was concluded that there was also additional unaccounted-for water in the ballast tanks during the previous test, and that the correction of 4.07 percent was insufficient. Although this discrepancy does not appear to be important, it serves to emphasize that in the prototype the amount of water required in the ballast tanks for a given tilt angle may be different from that indicated by the model tests. For this reason, it is recommended that the relation of tilt angle to the amount of water in the ballast tanks be determined by field tests before the mooring operations are begun, and that the correction obtained be used to modify other data of this report.

Figure 16 also shows the relation of tilt angle with the upper ballast tank filled 20, 40, 60, and 80 percent. Less water is required in the lower ballast tank for a given tilt angle when there is water in the upper tank, but the tilting operation depends mainly upon the amount of water in the lower tank. A critical tilt angle exists at about 10° where below this angle the amount of water in the upper tank does not affect the tilt appreciably. At lesser angles an increase of water in the upper ballast tank will decrease the tilt when the caisson is not moored. Where it is necessary to tilt the caisson more than 20°, the addition of a small quantity of water in the lower tank will cause a comparatively large increase in tilt, and the adjustments may require careful manipulation on the part of the operator. Also this condition is accentuated as the upper tank is filled, thus it may be well for the operator to perform the tilting operations with the upper tank nearly empty. (Amount depends on required wheel load on spillway and river water surface elevation.)

Determination of the Amount of Water Needed in Ballast Tanks

In the preliminary mooring tests it was demonstrated that the amount of water necessary in the ballast tanks during the mooring operation would depend upon the manner in which the caisson was moored, and upon the river water surface elevation. When it was attempted to study the problem further, it was found that the following factors were involved: (1) the river water surface elevation; (2) the amount of water in the lower ballast tank; (3) the amount of water in the upper ballast tank; (4) the angle of tilt of the caisson when floating; (5) the elevation or height to which the front end of the caisson lifts out of water to reach the mooring post; (6) the angle of tilt of the caisson when moored; (7) the force on the mooring post when moored; (8) the variation of force on the mooring post as the caisson is being pulled to the mooring post; (9) the force of the wheels against the spillway when moored; (10) the variation of force on the wheels when the caisson is being pulled to the mooring post; and (11) the effects of external influences such as extra weights on the caisson, or water in the upper side trim tank, or forces on the lateral control lines all of which are unknown.

In Factor 1, the water surface is independent of control and might be any value between elevations 935.0 and 945.0. Factor 11, the effect of the unknown external influences, will have to be considered at the time of the actual mooring of the prototype, and will not be discussed further in this report. Factors 2 and 3, the amounts of water in the ballast tanks are adjustable, thus making it possible to obtain desirable values of Factors 4 to 10 for given values of Factor 1. It follows that Factors 1, 2, and 3 are the independent variables and Factors 4 to 10 are the dependent variables. To determine the dependent variables tests were made by placing various quantities of water in the ballast tanks (Factors 2 and 3) and then measuring the angle of tilt and the height the caisson lifts out of water (Factors 4 and 5). Next, the caisson was moored with various water surface elevations, and Factors 6 to 10 were measured. The dependent variables were measured for the free floating and mooring operations with the lower ballast tank 7.49, 24.07, 44.07, 64.07, 69.07, 74.07, 79.07, 81.57, 84.07, and 86.57 percent full; the upper ballast tank 13.03, 18.73, 33.73, 48.73, 68.73, and 88.73 percent full, and water surface elevations of 935.0, 937.0, 939.0, 941.0, 943.0, and 945.0. Through these various combinations, it was possible to anticipate any operating condition which might arise.

Angle of Tilt Required for Mooring--Caisson Floating

One of the steps of the proposed mooring operation was to tilt the caisson sufficiently for the A-frame to reach the mooring post. It was anticipated that this operation could be accomplished only with the river water surface above elevation 936.0, because at the lower elevations the caisson would have to be tilted beyond 51°20', the spillway face angle. However, it was found that the model could not be tilted to reach the mooring post with the water surface below elevation 938.0, since the height to which the caisson could reach was dependent upon its weight. Figure 17 shows the required tilt angle for various water surface elevations. Two curves are shown, one for the estimated weight of 507,000 pounds for the prototype and the other for the model weight equivalent of 540,000 pounds. It was believed that the actual conditions will lie between these curves, and must be determined by the operators in the field. The operator must exercise caution in tilting the caisson when the water surface elevation is low to avoid tilting beyond the spillway slope of 51°20'; while on the other hand, he must avoid tilting the caisson further than necessary when the water surface is high. In that case the A-frame may have to be lowered to reach the mooring post, and as outlined in Instruction 4 of Figure 7, the peaking lines could be overloaded.

Angle of Tilt for Various Amounts of Water in Ballast Tank--Caisson Moored

It is believed that the caisson should never be tilted to the slope of the spillway until it is secured to the mooring post, and that the tilting after it is moored should proceed with the wheels held against the spillway so the lower end will not strike the spillway first and drag the seals. The angle of tilt of the caisson when moored depends upon the water surface elevation, and the amount of water in the upper and lower ballast tanks. Accordingly, in the detailed tests one step was to measure the tilt angle with the caisson moored. The data was arranged to give the dashed curves of Figure 8, which shows the relation of tilt angle in degrees to percent of water in the lower ballast tank for the upper ballast tank 10, 20, 40, 60, and 80 percent full. Curves are shown for water surface elevations 935.0, 937.0, 939.0, 941.0, 943.0, and 945.0. With the information given on Figure 8, any condition may be determined by interpolation.

Several limitations are imposed upon the curves of Figure 8. No information is shown for the lower ballast tanks less than 40 percent full, because all operations must be made with the lower tank 65 to 85 percent full or the loads on the mooring post will be excessive. The curves were not extended beyond the point where the lower tank was 85 percent full although the tilt angle of $51^{\circ}20'$ was not reached in every case. This was because, if the vertical tilt angle was not reached, there would be an upward thrust of the A-frame against the mooring post with the tank more than 85 percent full. In correcting for the excess weight of the model it was assumed that the upper tank was 13.03 percent full, and a curve for the empty condition would have to be obtained by extrapolation. However, the data did not warrant this for it was of such a nature that the curves shown for the tank 10 percent full might also be used as the 0 percent curves without excessive error.

Force on Mooring Post for Different Tail Water Elevations and Various Amounts of Water in Ballast Tanks

In addition to showing the angle of tilt when moored, Figure 8 shows the force on the mooring post for the various combinations of water surface elevations and amounts of water in the tanks. It is emphasized that the forces are greater than the designated strength of the mooring post and A-frame, 65,000 pounds, whenever the lower ballast tank is less than 65 percent full, and that under certain conditions this force became zero with the lower tank about 80 to 84 percent full. The force curves for different amounts of water in the upper ballast tank followed a definite pattern, the forces decreasing rapidly as the lower tank was filled until the tilt of the caisson was $51^{\circ}20'$. The forces increased rapidly with further amounts of water in the lower ballast tank, for the caisson was resting against the spillway and the additional amounts of water acted directly upon the mooring post.

Force Required to Pull Caisson up the Face of the Spillway to Mooring Post

If it is found expedient to pull the caisson up the spillway face to the mooring post, it is necessary to know the pulling forces required. Therefore, for each of the combinations of water quantities in the upper and lower ballast tanks and the different river water surface elevations, the model caisson was slowly pulled to the mooring post, and the pulling force on the A-frame measured. This pulling force remained surprisingly constant during the mooring operation. As soon as the caisson was lifted a small distance out of the water, the pull increased to approximately that required to hold it in final position to the mooring post, and the magnitude did not change appreciably as it was pulled up the spillway face. Thus for given amounts of water in the ballast tanks, the pull is independent of the water surface elevation. However, as demonstrated by the model, if the mooring operation proceeds too fast the pull may increase as much as 100 percent because the tilt angle might not change rapidly enough to establish the balance with the pulling force. Moreover, if the operation proceeds too fast, the caisson will likely rock about the wheels after it is moored and cause a considerable fluctuation of force on the mooring post.

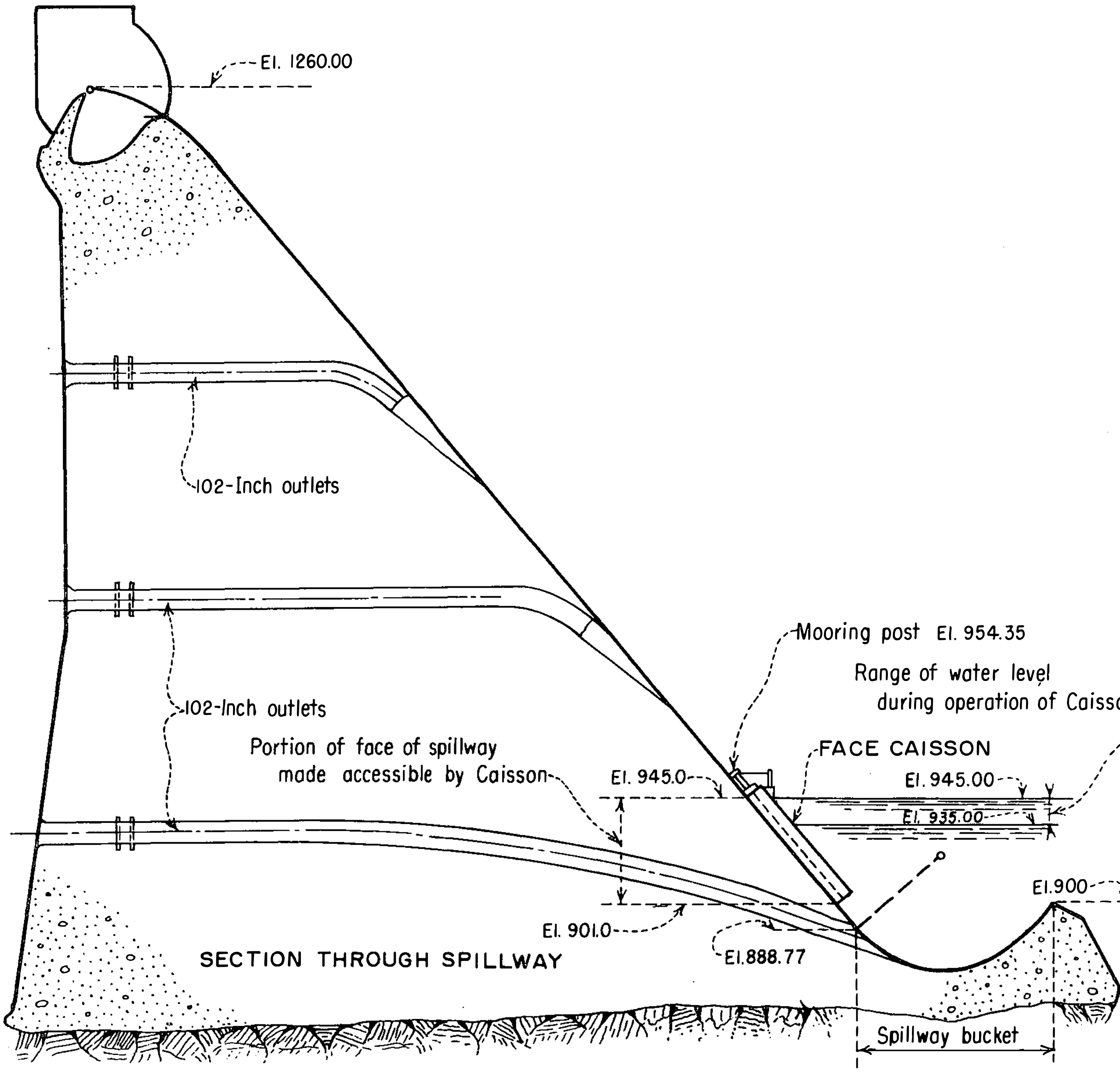
It was concluded from these observations that the force to pull the caisson to the mooring post will be practically the same as the force when moored, and that the force curves of Factor 7 will be applicable (Figure 8). However, these conditions hold only when the angle of tilt does not become so great as to cause the caisson to drag against the spillway surface.

Force Exerted on Face of the Spillway by Caisson Wheels when Caisson is Moored

The desirability of having the wheels in contact with the spillway has been discussed previously, and accordingly, the wheel loads were measured at the same time that the forces on the mooring post and the forces to pull the caisson to the mooring post were measured. These measurements were made by lifting a wheel just off the spillway with a small spring scale. It was found that the load on the two wheels was approximately 100 to 120 percent of the force on the mooring post at all times. Therefore, it may be concluded that for all practical purposes the force of both wheels against the spillway will be the same as the pull on the mooring post, and that the approximate wheel load is given by the curves of Figure 8.

Figure 1

The Grand Coulee Dam



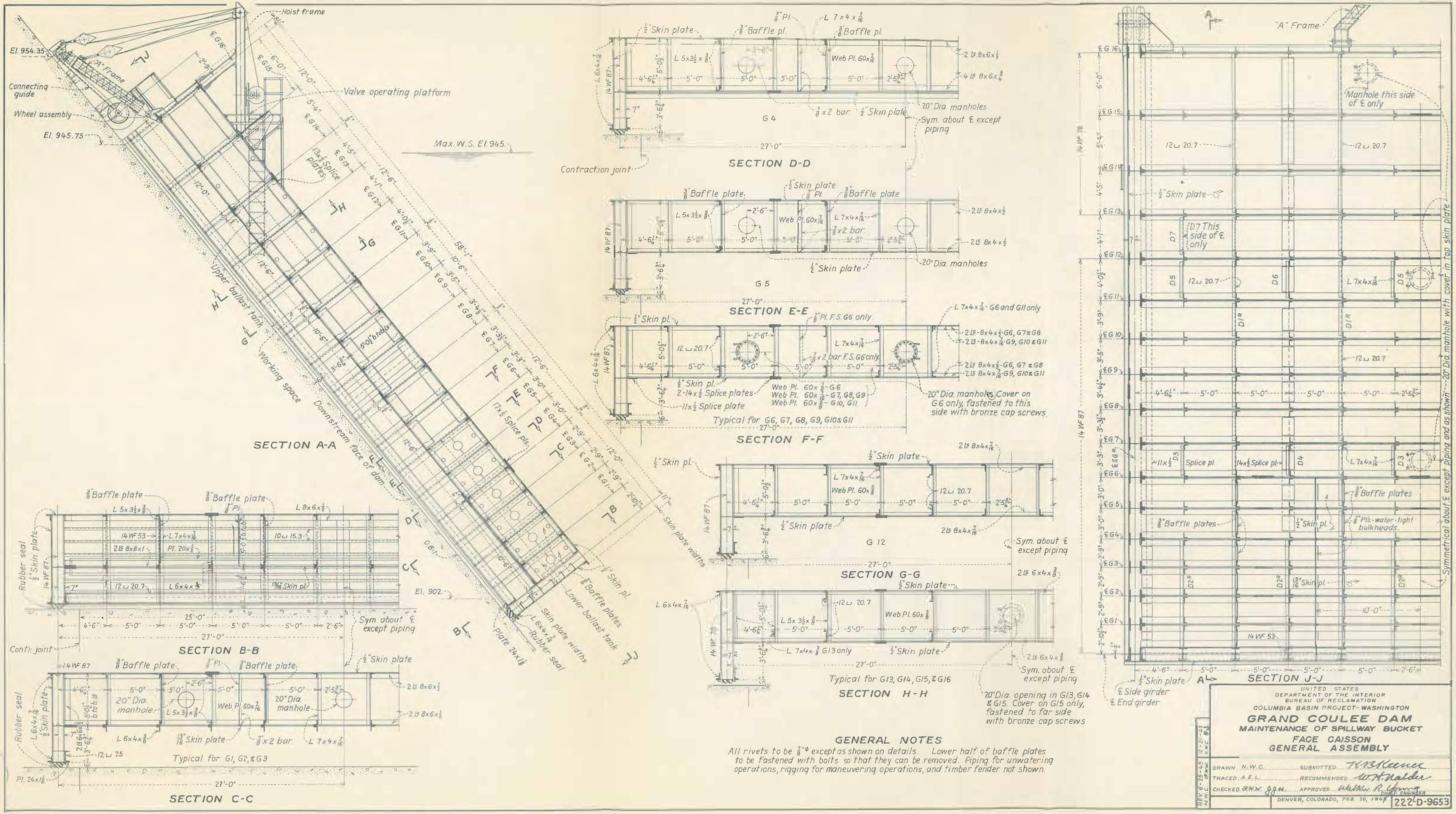
COLUMBIA BASIN PROJECT-WASHINGTON

GRAND COULEE DAM

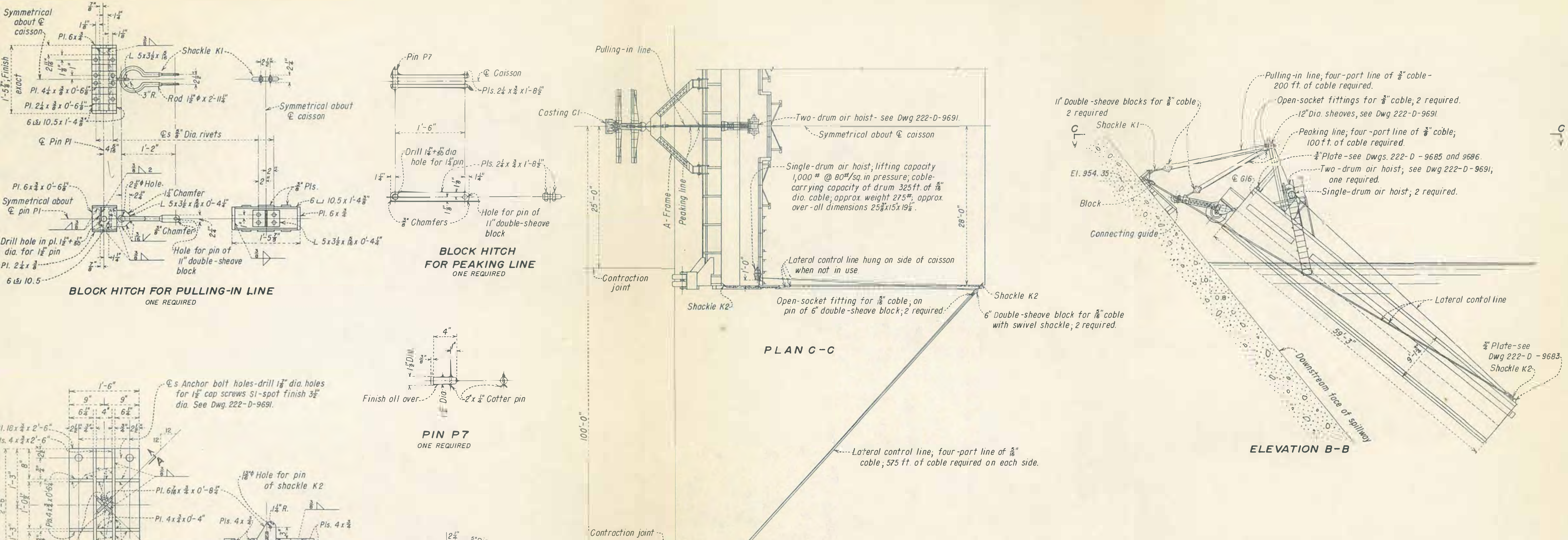
HYDRAULIC STUDIES ON 1:20 MODEL
OF SPILLWAY FACE CAISSON

POSITION OF CAISSON ON SPILLWAY FACE

FIGURE 3



SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
Hoist frame
"A" Frame
Connecting guide
Wheel assembly
El. 954.35
El. 945.75
Valve operating platform
Max. W.S. El. 945.
Upper ballast tank
Working space
Downstream face of dam
Lower ballast tank
Skin plate widths
Rubber seal
Plate 24x1⅛
El. 902.
Contraction joint
Contr. joint
Sym. about ℄ except piping
Typical for G1, G2, & G3
Typical for G6, G7, G8, G9, G10 & G11
Typical for G13, G14, G15, & G16
20" Dia. manholes
Manhole this side of ℄ only
Symmetrical about ℄ except piping and as shown
20" Dia. manhole with cover in top skin plate
℄ Side girder
℄ End girder
GENERAL NOTES
All rivets to be ⅞"Φ except as shown on details. Lower half of baffle plates to be fastened with bolts so that they can be removed. Piping for unwatering operations, rigging for maneuvering operations, and timber fender not shown.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
GRAND COULEE DAM
MAINTENANCE OF SPILLWAY BUCKET
FACE CAISSON
GENERAL ASSEMBLY
DRAWN N.W.C.
TRACED A.E.L.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHIEF ENGINEER
DENVER, COLORADO, FEB. 20, 1945
222-D-9653



NOTES

All sheaves are to be furnished with self-lubricating bushings.

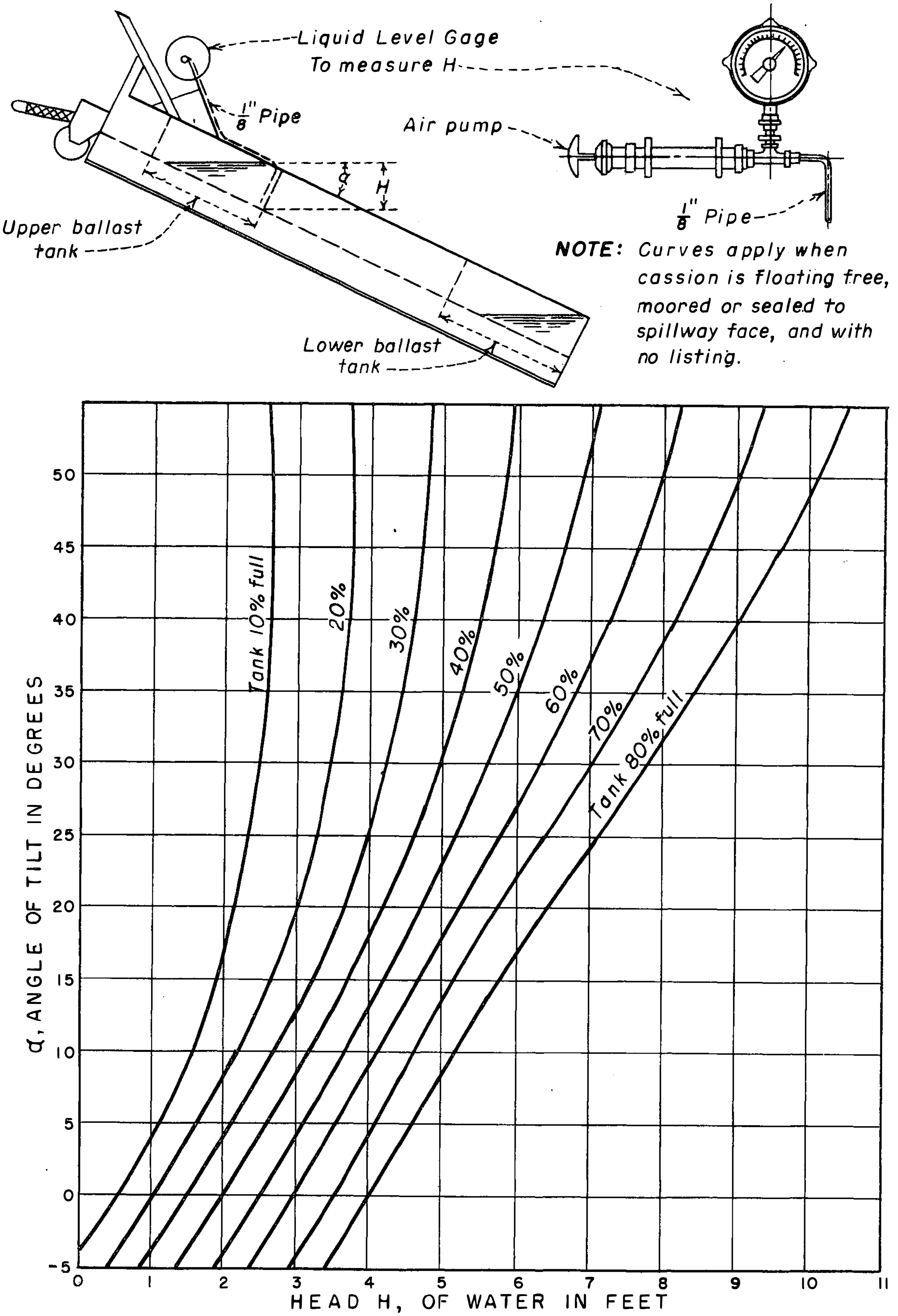
REFERENCE DRAWINGS

FACE CAISSON-GENERAL ASSEMBLY 222-D-9653
FLOATING CAISSON-A-FRAME-ANCHOR BOLTS 222-D-9634
FUSION WELDING SYMBOLS X-D-2589

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON

GRAND COULEE DAM
MAINTENANCE OF SPILLWAY
FACE CAISSON
RIGGING ARRANGEMENT

DRAWN H.R.O. SUBMITTED [signature]
TRACED G.L.P.-E.M.W. RECOMMENDED [signature]
CHECKED [initials] APPROVED [signature] CHIEF ENGINEER
DENVER, COLORADO, JUNE, 13 1945 222-D-9712



COLUMBIA BASIN PROJECT-WASHINGTON

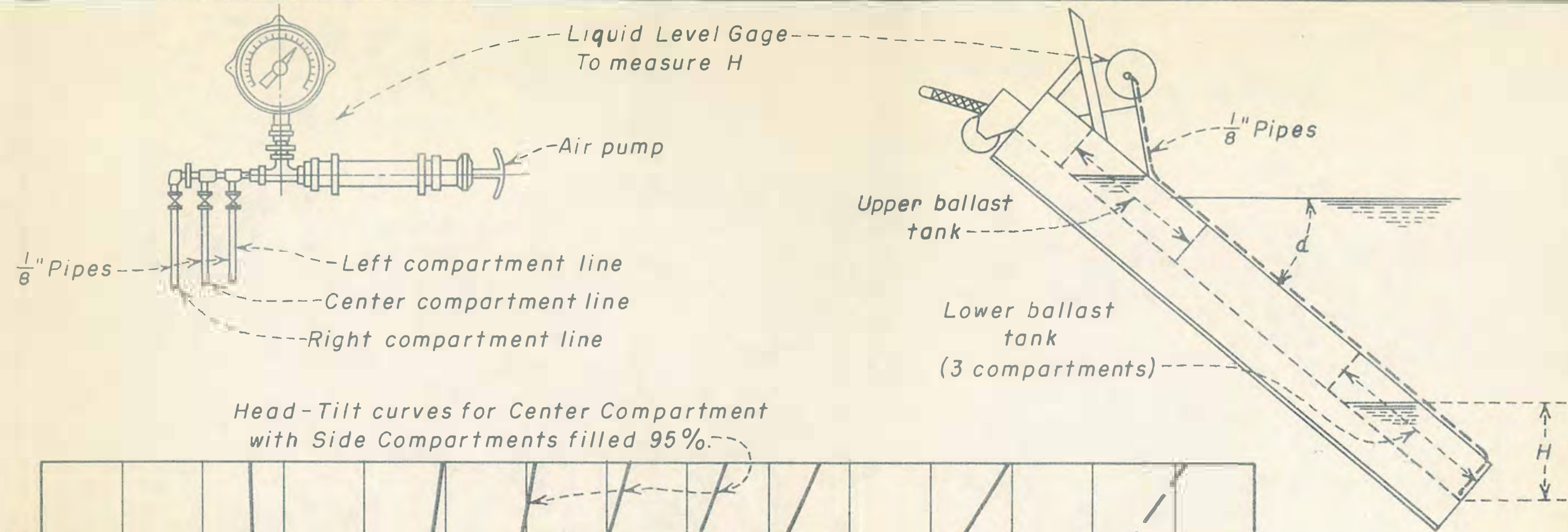
GRAND COULEE DAM

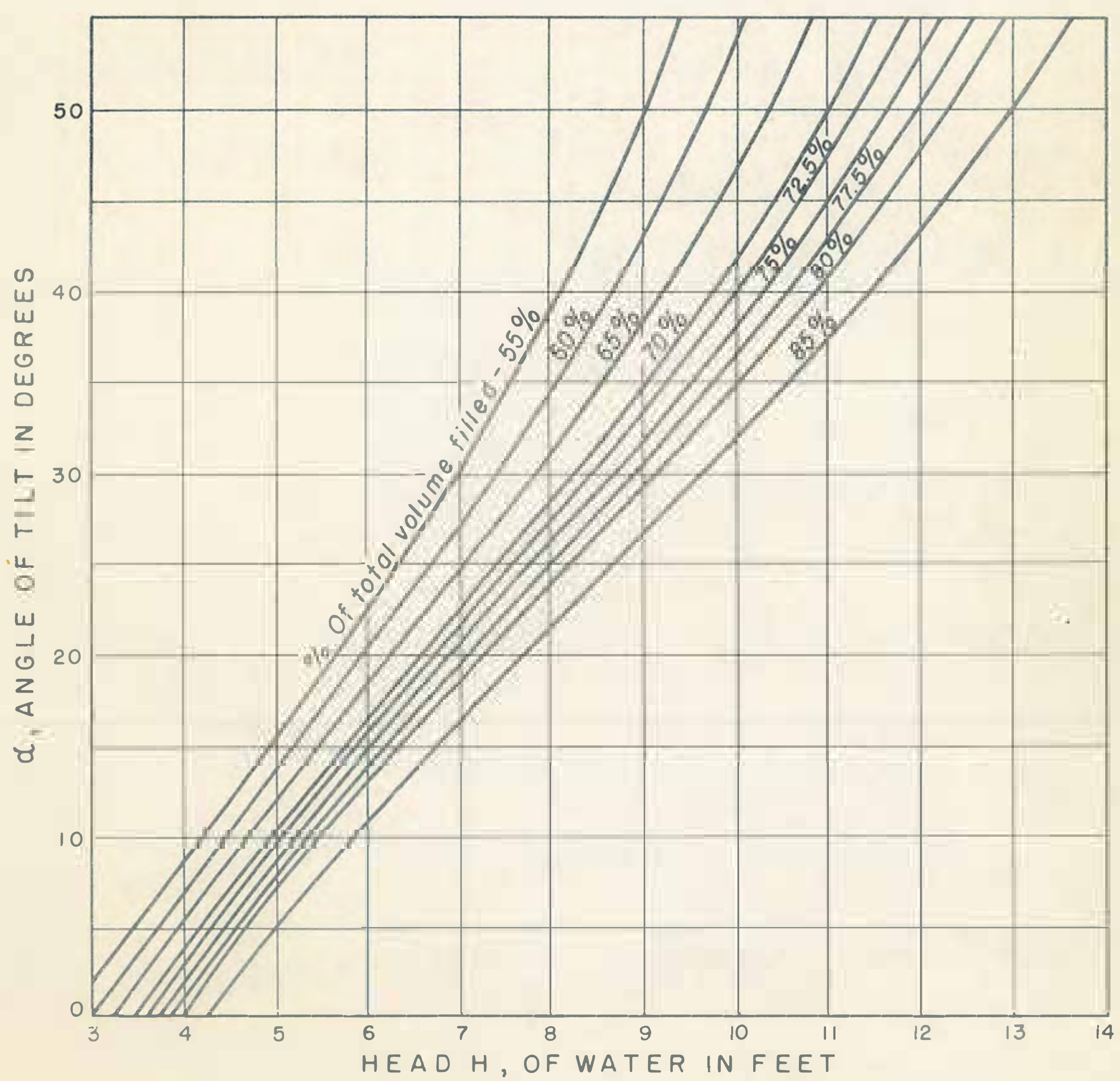
SPILLWAY FACE CAISSON

DETERMINATION OF AMOUNT OF WATER IN UPPER BALLAST TANK

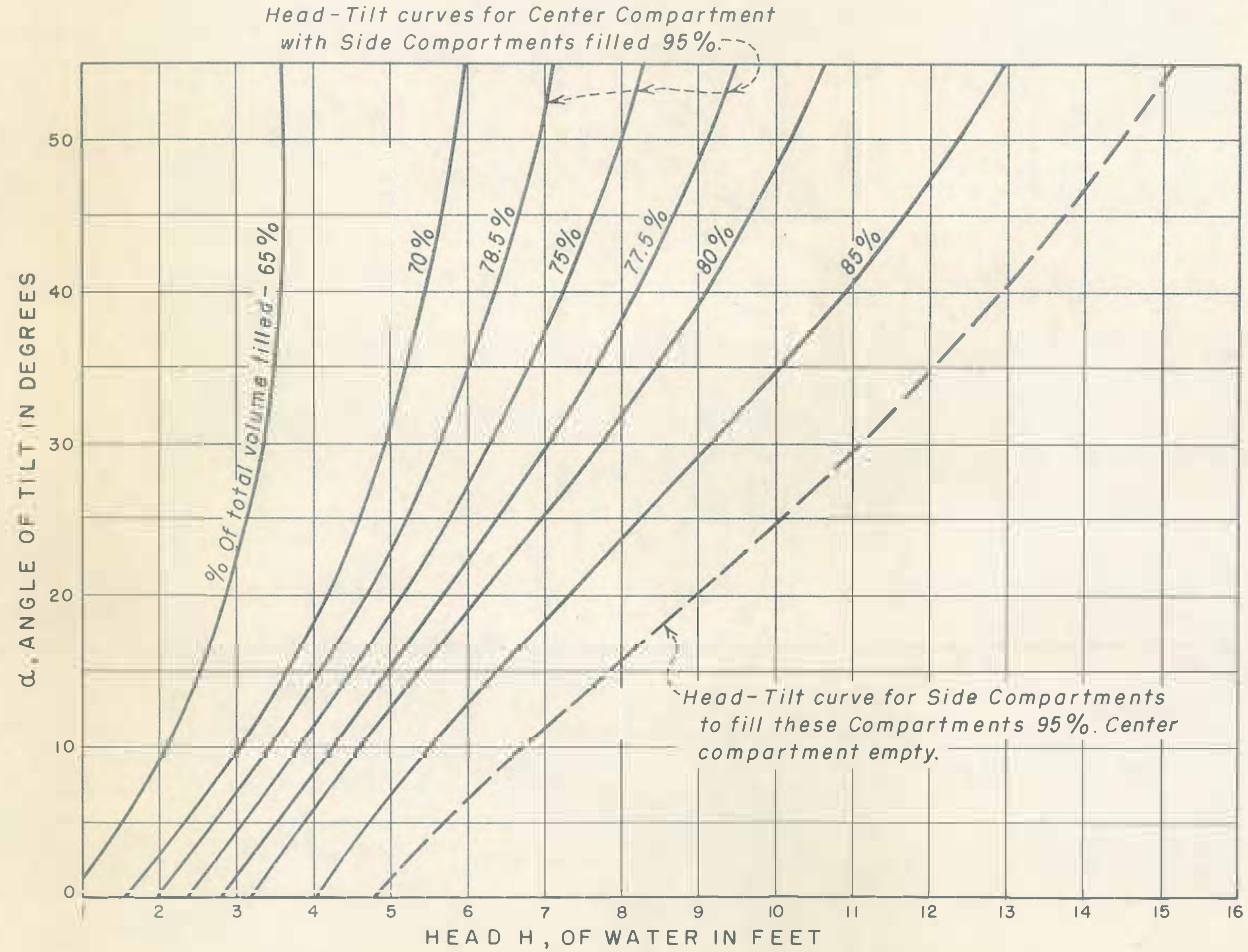
FIGURE 6

NOTE: Curves apply when caisson is floating free, moored or sealed to spillway face, and with no listing.





CASE 1 - WHERE H IS SAME IN ALL COMPARTMENTS



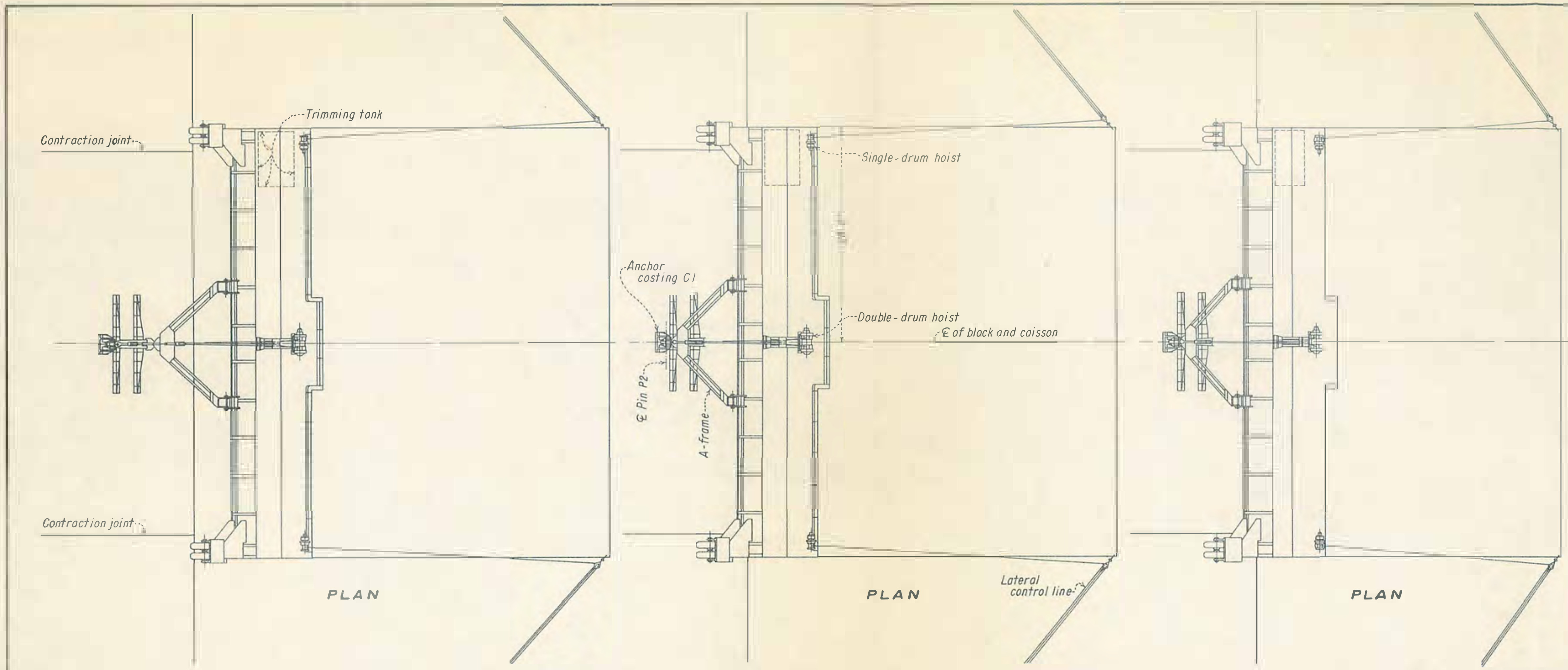
CASE 2 - SIDE COMPARTMENTS 95% FULL, ADJUSTMENTS BY CENTER COMPARTMENT

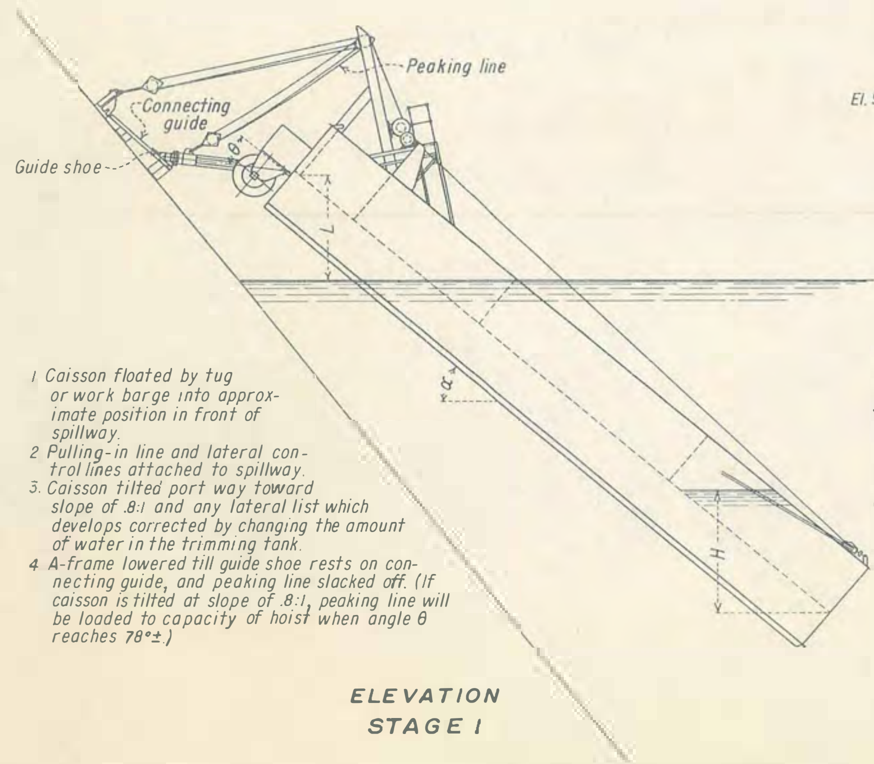
COLUMBIA BASIN PROJECT-WASHINGTON

GRAND COULEE DAM

SPILLWAY FACE CAISSON

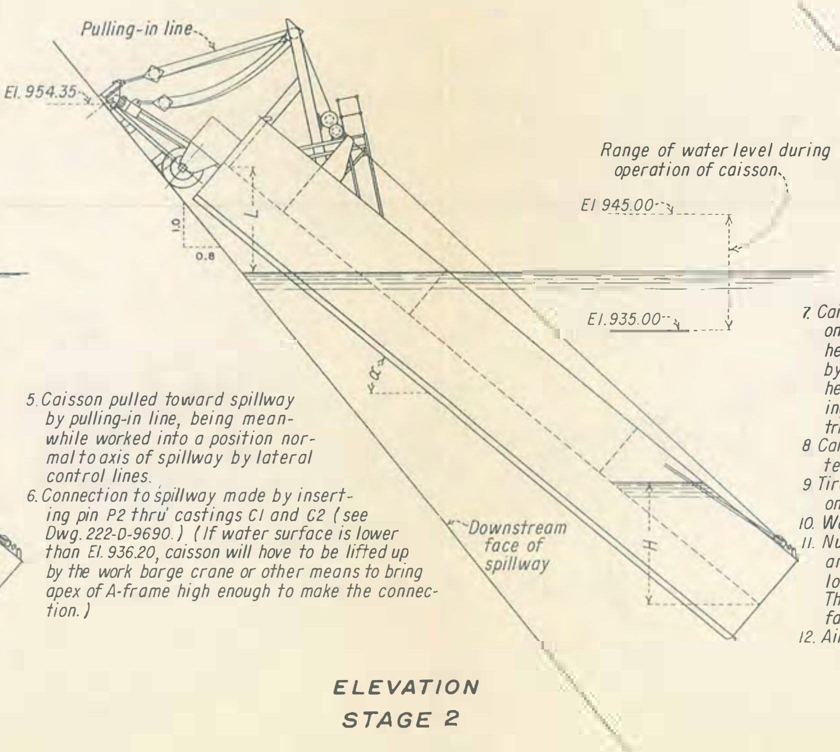
DETERMINATION OF AMOUNT OF WATER IN LOWER BALLAST TANK





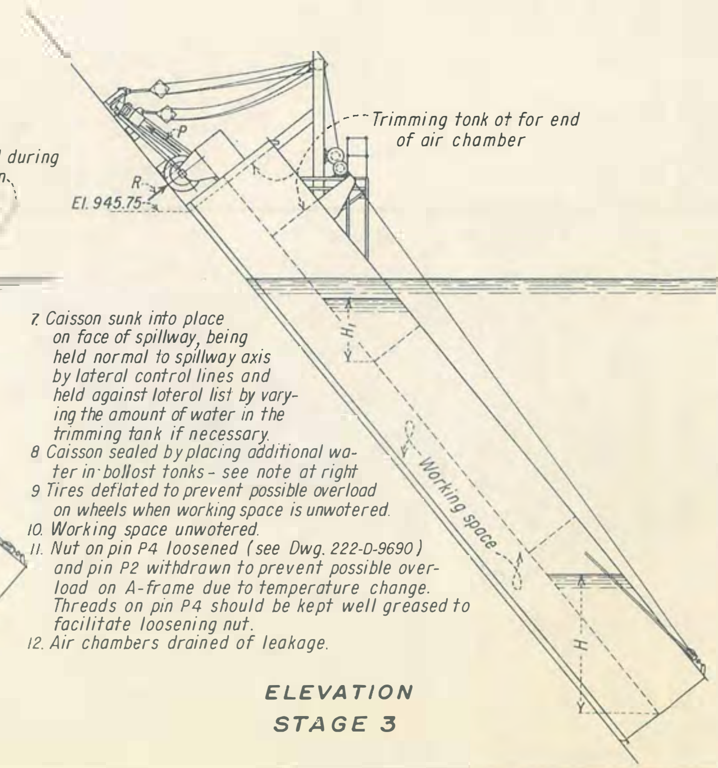
ELEVATION
STAGE 1

1 Caisson floated by tug or work barge into approximate position in front of spillway.
2 Pulling-in line and lateral control lines attached to spillway.
3. Caisson tilted part way toward slope of .8:1 and any lateral list which develops corrected by changing the amount of water in the trimming tank.
4 A-frame lowered till guide shoe rests on connecting guide, and peaking line slacked off. (If caisson is tilted at slope of .8:1, peaking line will be loaded to capacity of hoist when angle θ reaches 78°±)



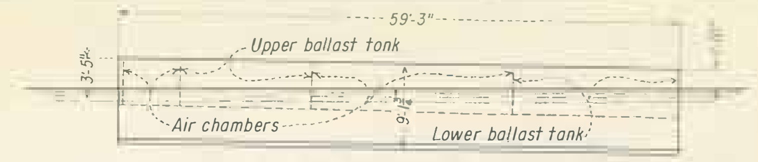
ELEVATION
STAGE 2

5. Caisson pulled toward spillway by pulling-in line, being meanwhile worked into a position normal to axis of spillway by lateral control lines.
6. Connection to spillway made by inserting pin P2 thru' castings C1 and C2 (see Dwg. 222-D-9690.) (If water surface is lower than El. 936.20, caisson will have to be lifted up by the work barge crane or other means to bring apex of A-frame high enough to make the connection.)

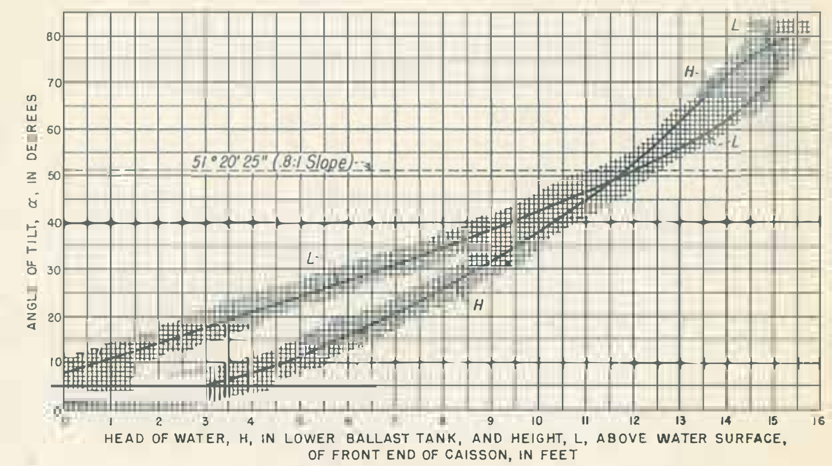


ELEVATION
STAGE 3

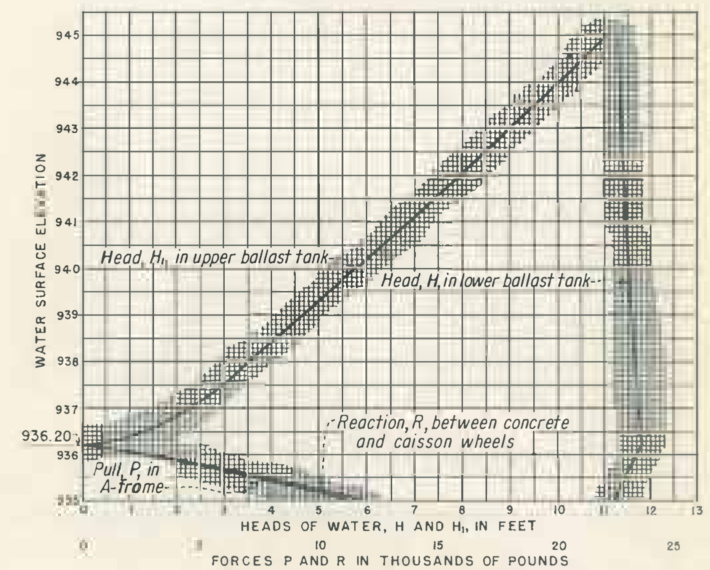
7. Caisson sunk into place on face of spillway, being held normal to spillway axis by lateral control lines and held against lateral list by varying the amount of water in the trimming tank if necessary.
8 Caisson sealed by placing additional water in ballast tanks - see note at right
9 Tires deflated to prevent possible overload on wheels when working space is unwatered.
10. Working space unwatered.
11. Nut on pin P4 loosened (see Dwg. 222-D-9690) and pin P2 withdrawn to prevent possible overload on A-frame due to temperature change. Threads on pin P4 should be kept well greased to facilitate loosening nut.
12. Air chambers drained of leakage.



NORMAL FLOATING POSITION OF CAISSON
(NO WATER IN EITHER BALLAST TANK)



BALLAST REQUIRED TO TILT CAISSON
(NO WATER IN UPPER BALLAST TANK)



BALLAST REQUIRED TO SINK CAISSON INTO PLACE ON SPILLWAY FACE

For water surfaces at and above El. 936.20, water added in ballast tanks, for sealing the caisson, to a total depth of 3.6 ± feet in excess of $(H+H_1)$ will load the A-frame to its designed capacity of 65,000 pounds. For water surfaces below El. 936.20, the allowable total depth of water used for sealing must be reduced by .000056 times initial pull, P, in the A-frame.

GENERAL NOTES

Before placing operations are undertaken the lateral list of the caisson should be corrected by partially filling the trimming tank.

The curves shown on this drawing are subject to some modification due to the weight of the trim, to deviation of the actual weight of the caisson from the calculated weight, and to differences between the actual and calculated distribution of weight.

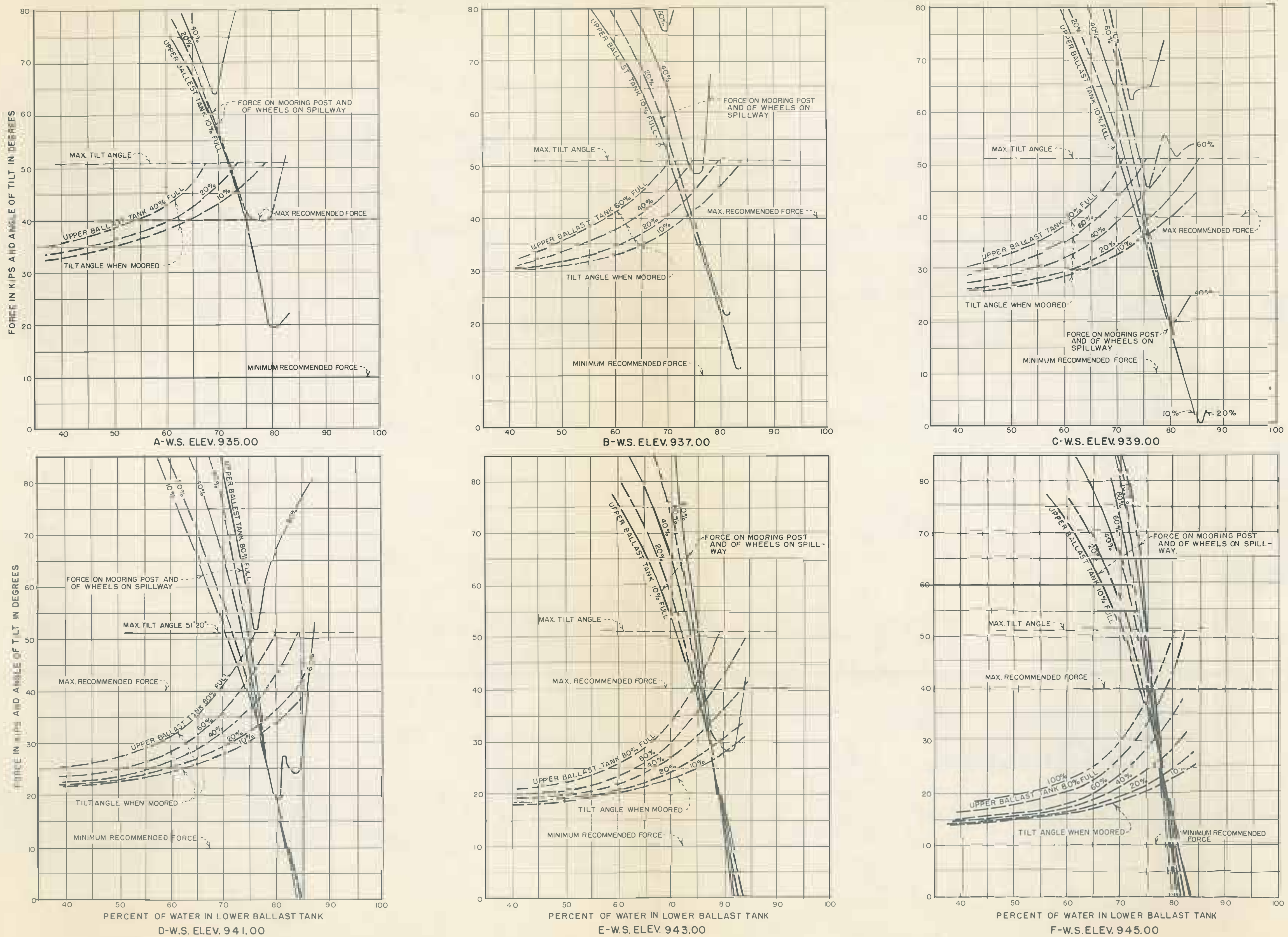
REFERENCE DRAWING

FACE CAISSON - RIGGING ARRANGEMENT.... 222-D-9712

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON

GRAND COULEE DAM
MAINTENANCE OF SPILLWAY
FACE CAISSON PLACING OPERATIONS

DRAWN H.R.O. - N.W.C. SUBMITTED T.B. Keener
TRACED C.I.H. - V.F.S. RECOMMENDED W.H. Nalder
CHECKED R.N.W. APPROVED Walker R. Young CHIEF ENGINEER
DENVER, COLORADO, JUNE 27, 1945 222-D-9722

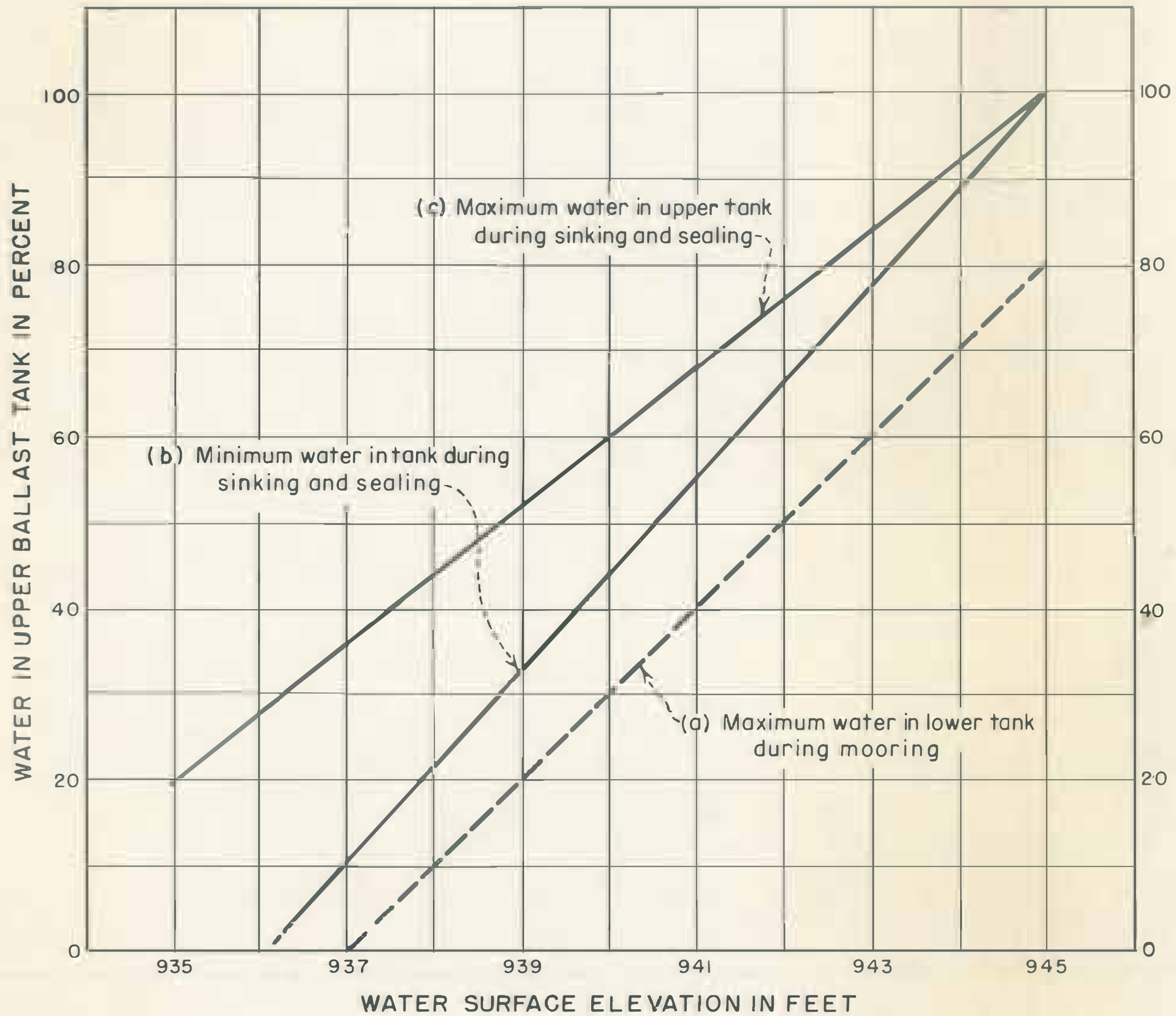


COLUMBIA BASIN PROJECT WASHINGTON

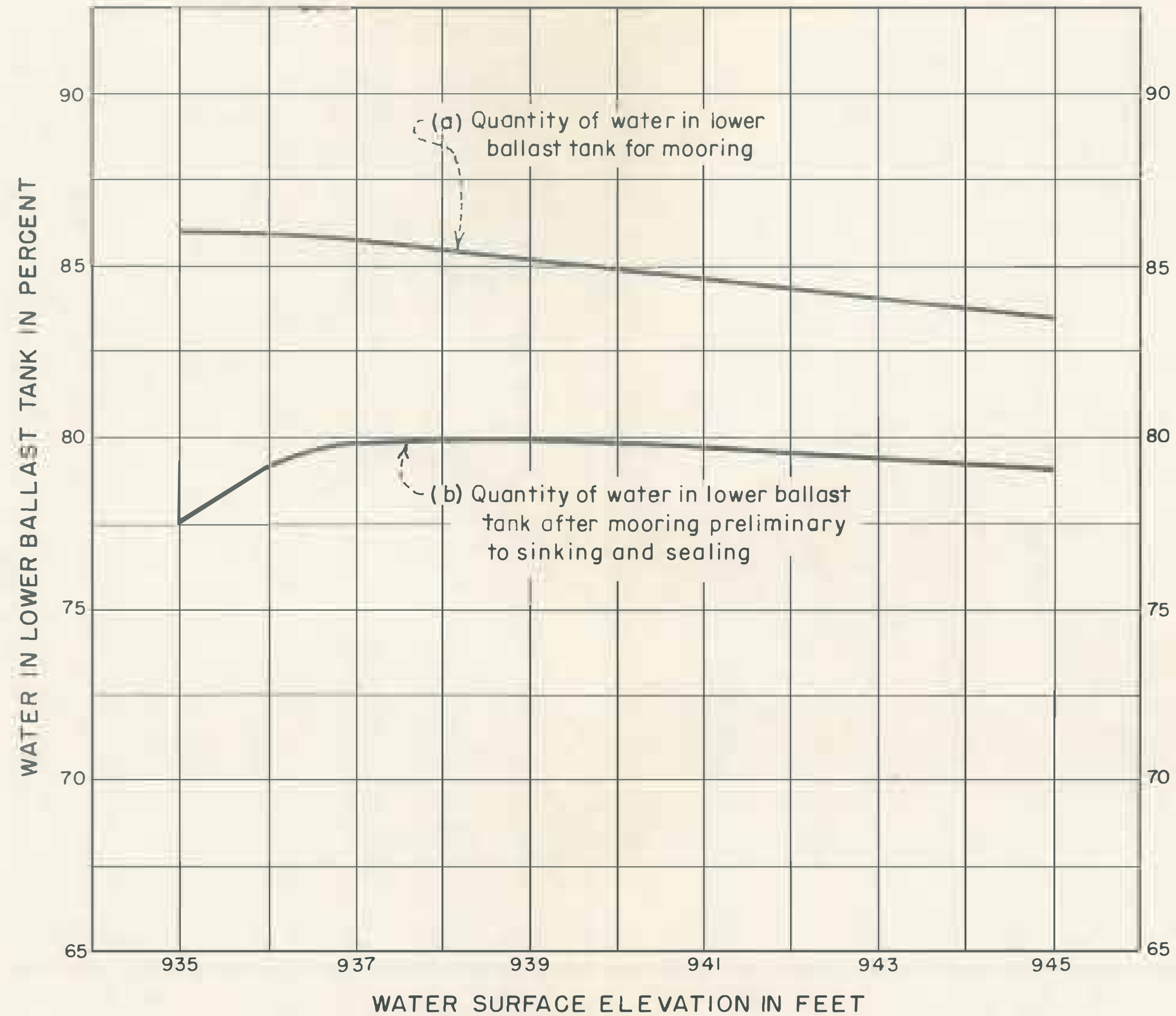
GRAND COULEE DAM

HYDRAULIC STUDIES ON 1:20 MODEL
OF SPILLWAY FACE CAISSON

EFFECT OF BALLAST WATER ON THE
MOORING FORCES AND TILT ANGLES



A-LIMITATIONS OF WATER IN UPPER BALLAST TANK

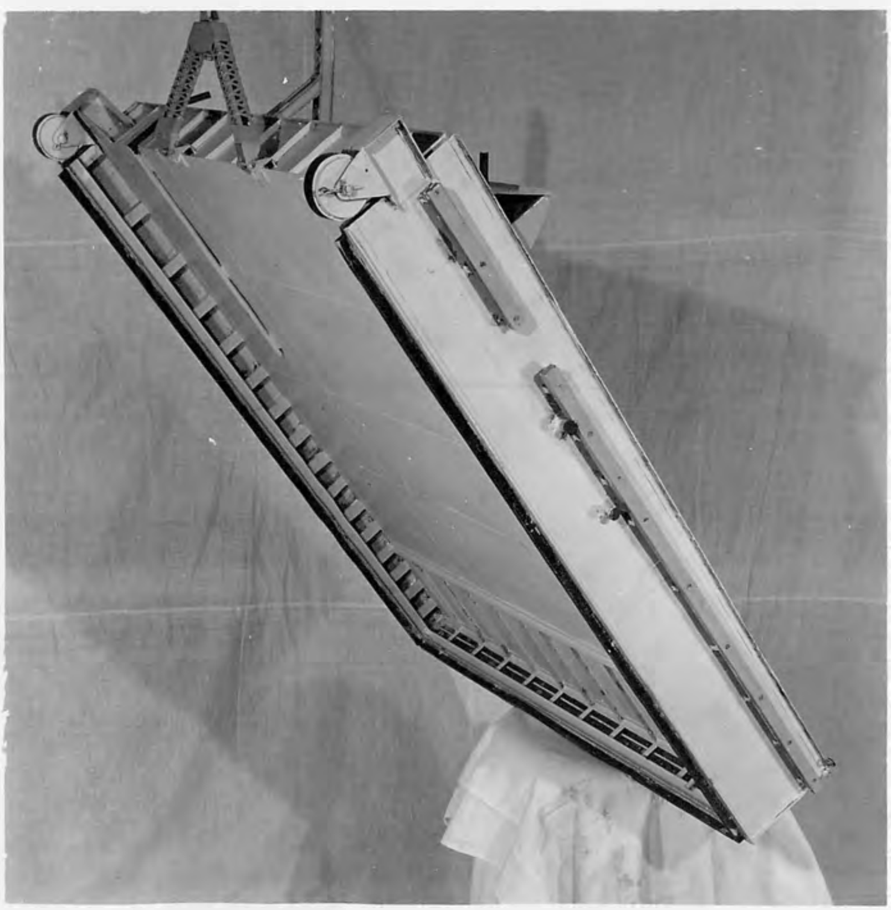


B-LIMITATIONS OF WATER IN LOWER BALLAST TANK

GRAND COULEE SPILLWAY FACE CAISSON

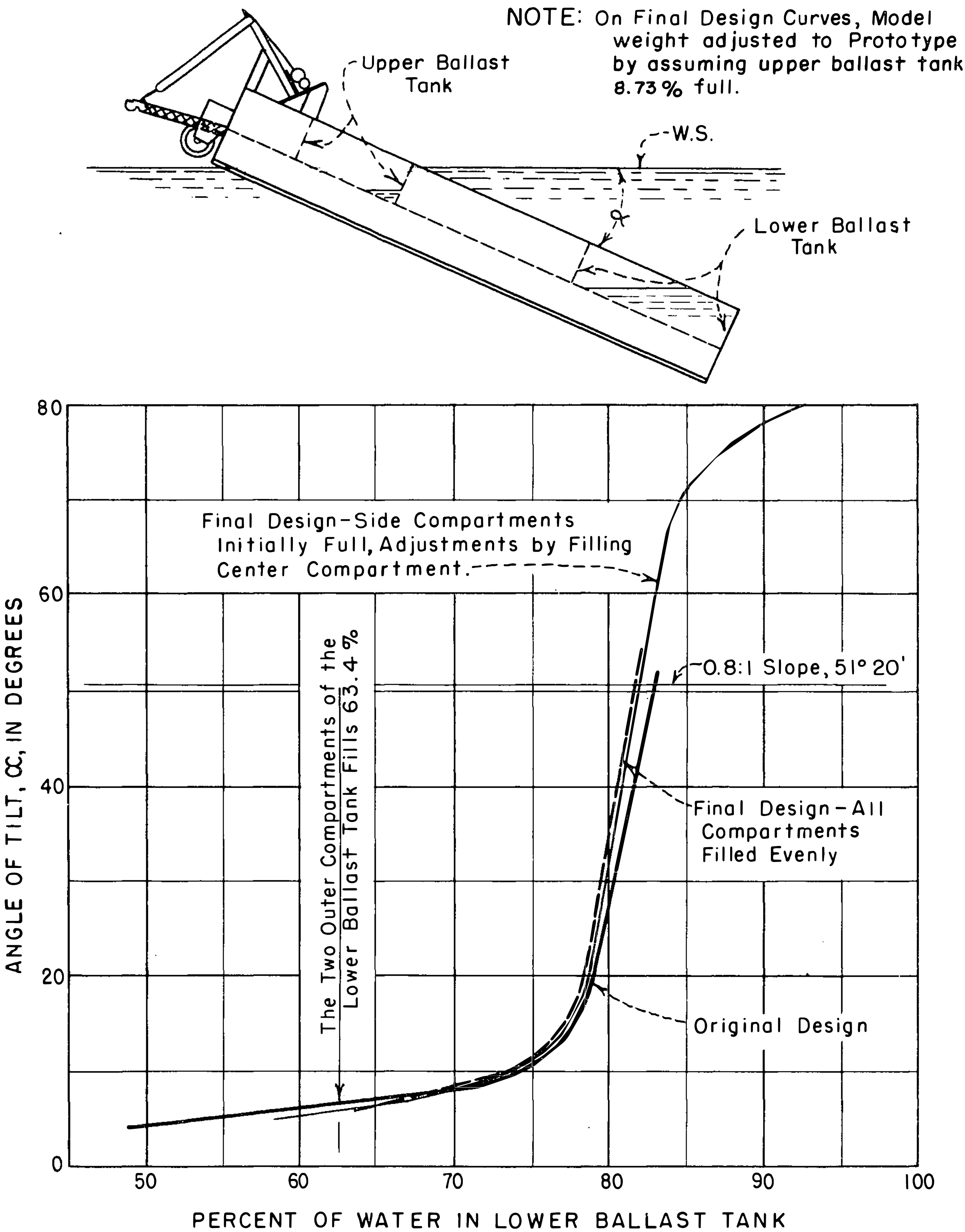
COLUMBIA BASIN PROJECT-WASHINGTON
GRAND COULEE DAM
HYDRAULIC STUDIES ON 1:20 MODEL
OF SPILLWAY FACE CAISSON
QUANTITY OF WATER IN BALLAST TANKS
FOR MOORING AND SEALING

A. Top of caisson from left front corner.



B. Caisson tilted to show working space on under side.

Grand Coulee Spillway Face Caisson
1:20 Scale Model

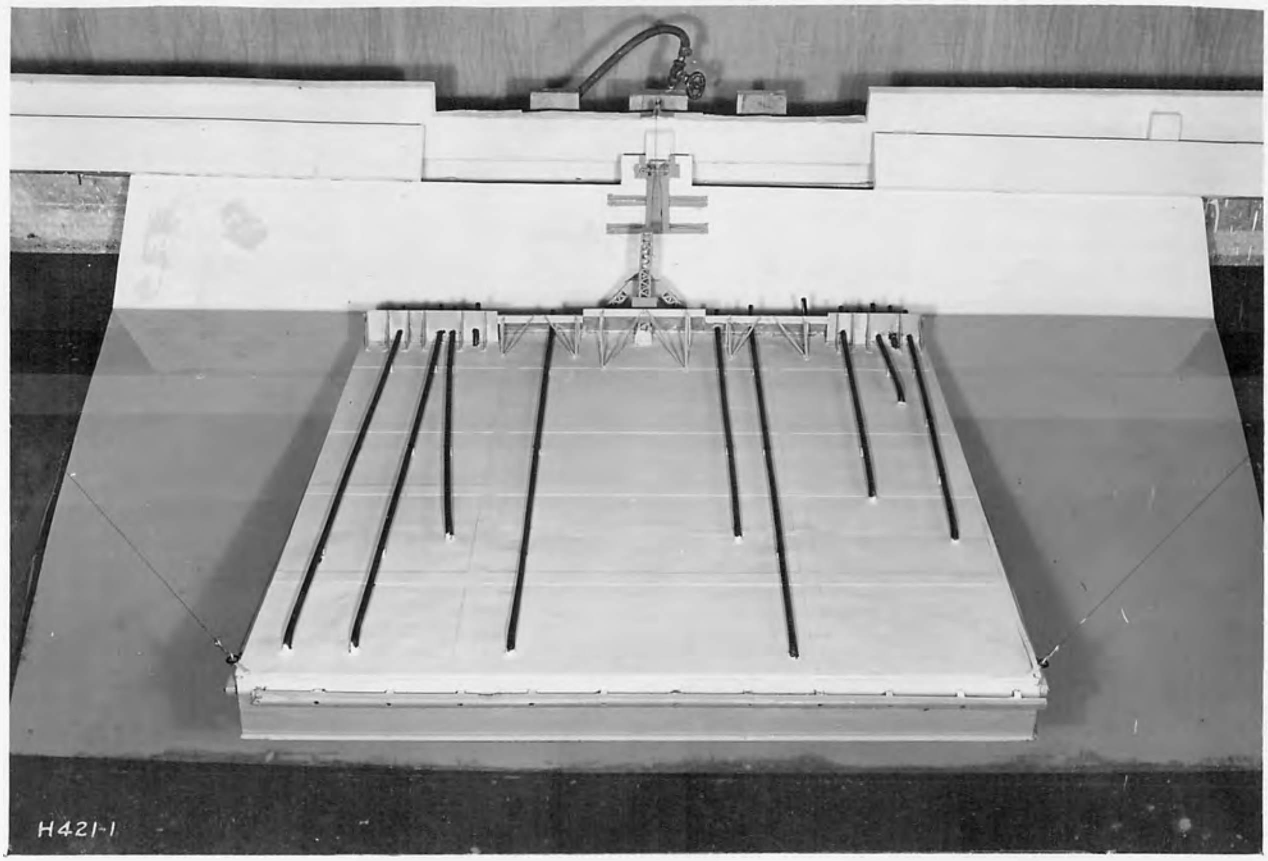


COLUMBIA BASIN PROJECT-WASHINGTON

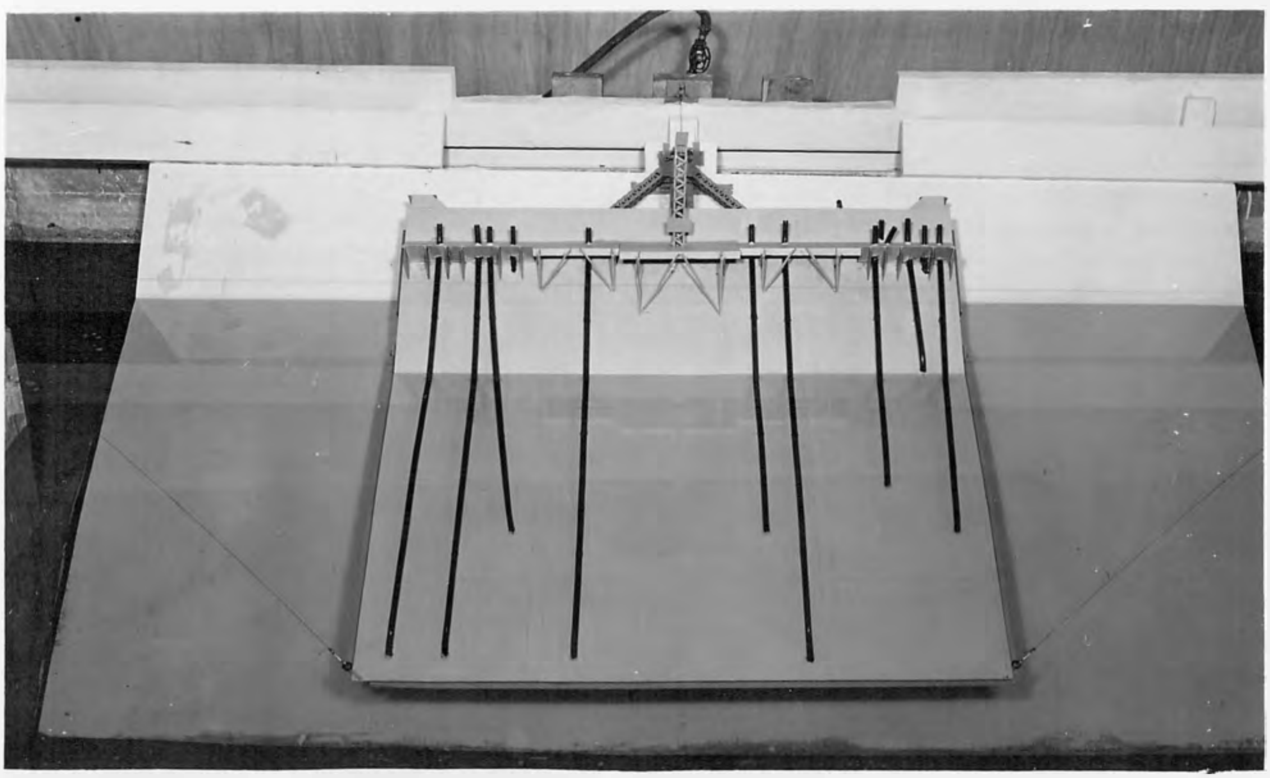
GRAND COULEE DAM

HYDRAULIC STUDIES ON 1:20 MODEL OF SPILLWAY FACE CAISSON

RELATION OF TILT TO WATER IN LOWER BALLAST TANK

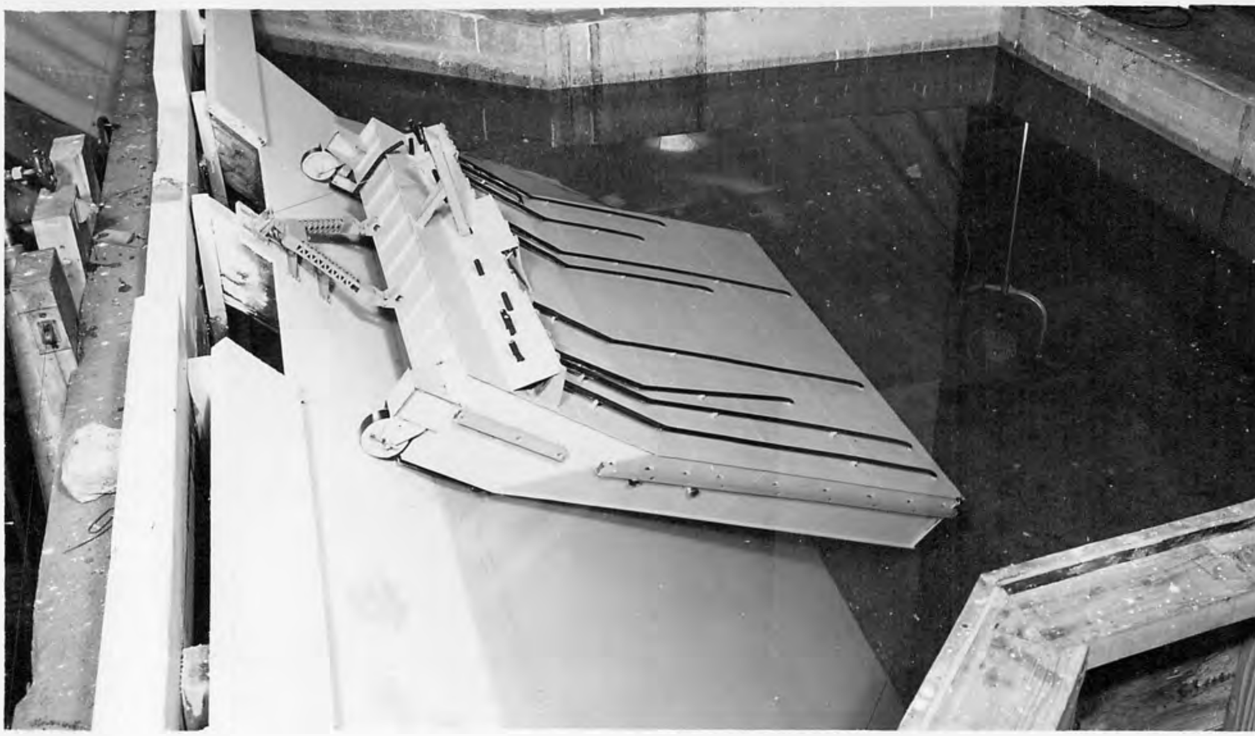


A. Caisson floating in position for mooring.



B. Caisson tilted for mooring by placing water in lower ballast tank.

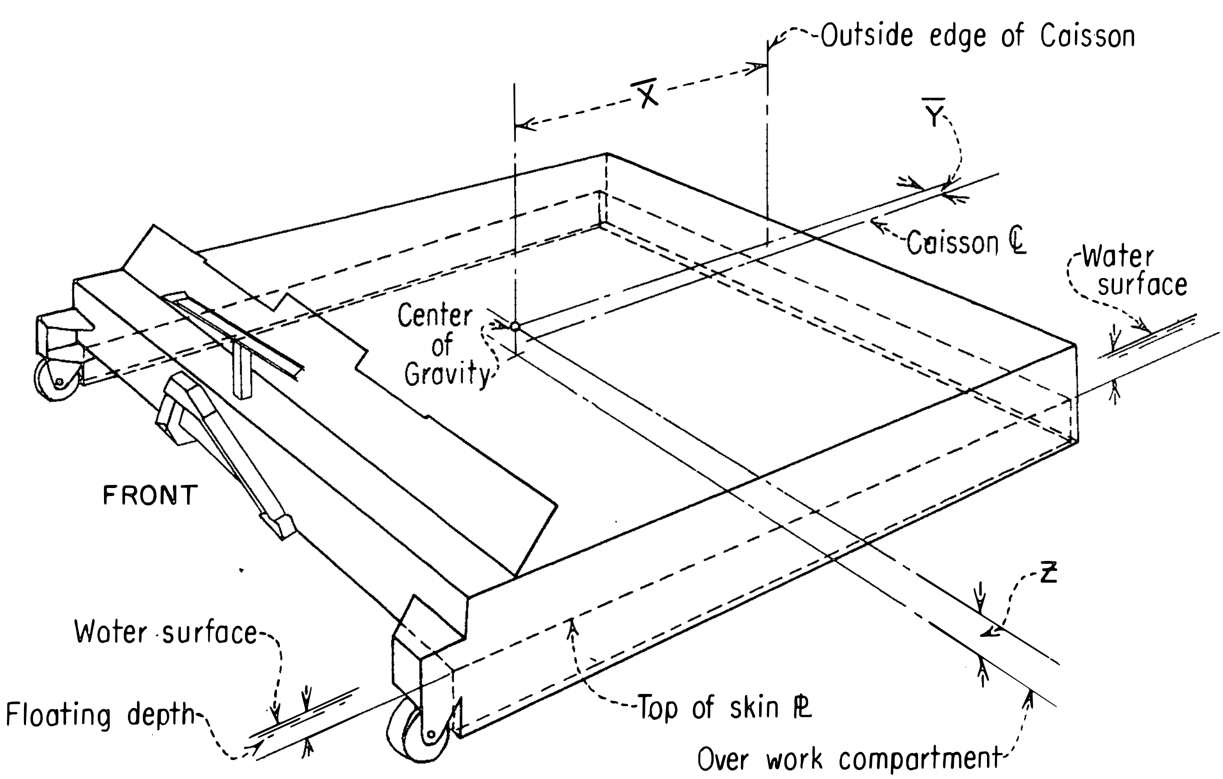
Mooring of Grand Coulee Spillway Face Caisson
to face dam. 1:20 Scale Model



A. Caisson attached to mooring post ready for sinking operation.

B. Caisson sealed preparatory to unwatering work chamber.

Sinking Grand Coulee Spillway Face Caisson
in place on spillway face. 1:20 Scale Model



A. WEIGHT OF CAISSON

1. Prototype design value	507,000 Pounds
2. Final model	540,000 Pounds

B. CENTER OF GRAVITY

X̄	1. Prototype design value	26.67 Ft.
	2. Final model	27.0 Ft.
Ȳ	1. Prototype design value	0.0
	2. Final model	0.1 Ft.
Z̄	1. Prototype design value	2.08 Ft.
	2. Final model	2.00 Ft.

C. FLOATING DEPTH

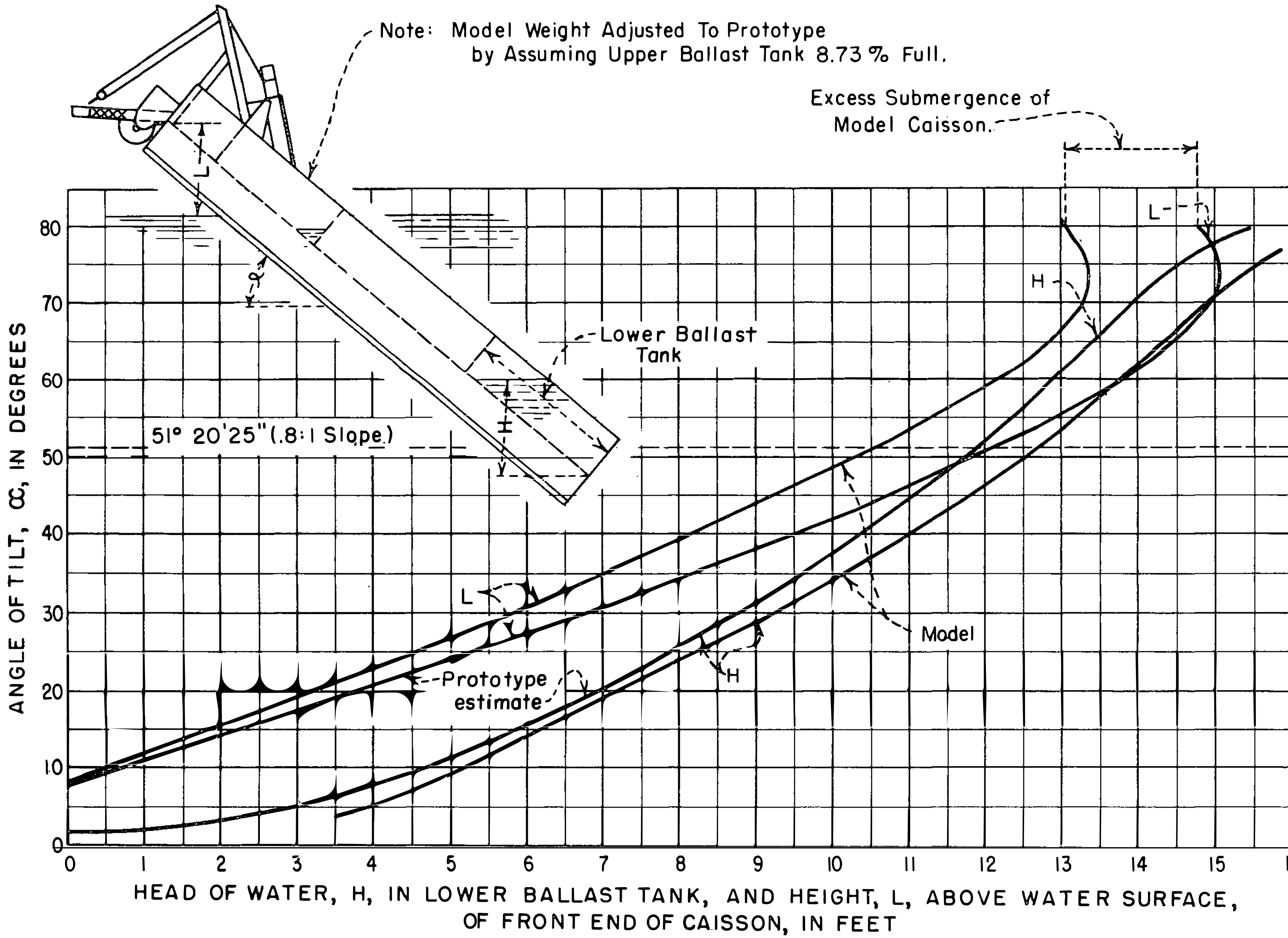
FRONT	1. Prototype design value		1.67 Ft.
	2. Final model	Left side	1.91 Ft.
		Right side	1.90 Ft.
REAR	1. Prototype design value		3.28 Ft.
	2. Final model	Left side	3.33 Ft.
		Right side	3.17 Ft.

COLUMBIA BASIN PROJECT - WASHINGTON

GRAND COULEE DAM

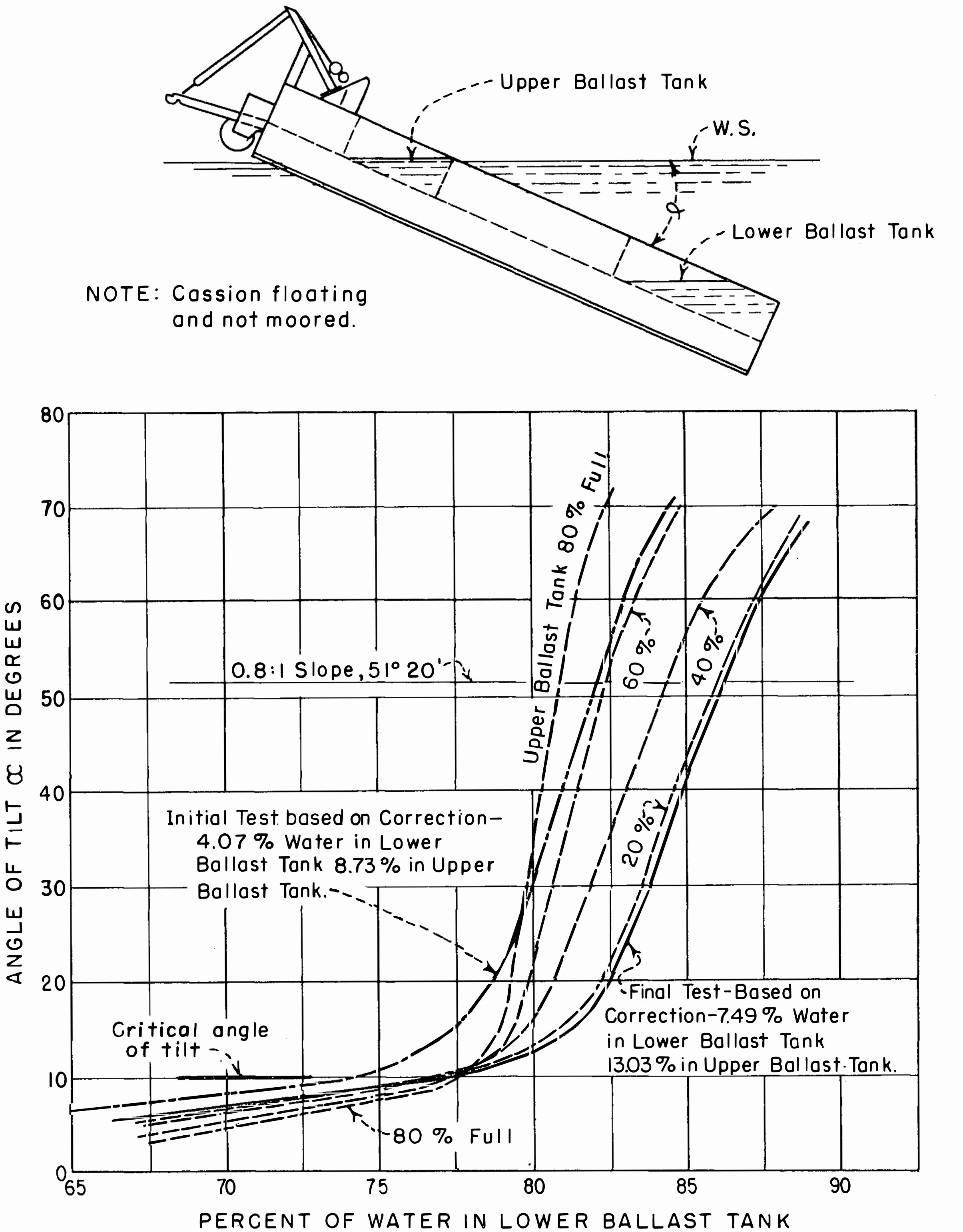
HYDRAULIC STUDIES ON 1:20 MODEL
OF SPILLWAY FACE CAISSON

COMPARISON OF MODEL WITH
PROTOTYPE DESIGN



BALLAST REQUIRED TO TILT CAISSON

FIGURE 15

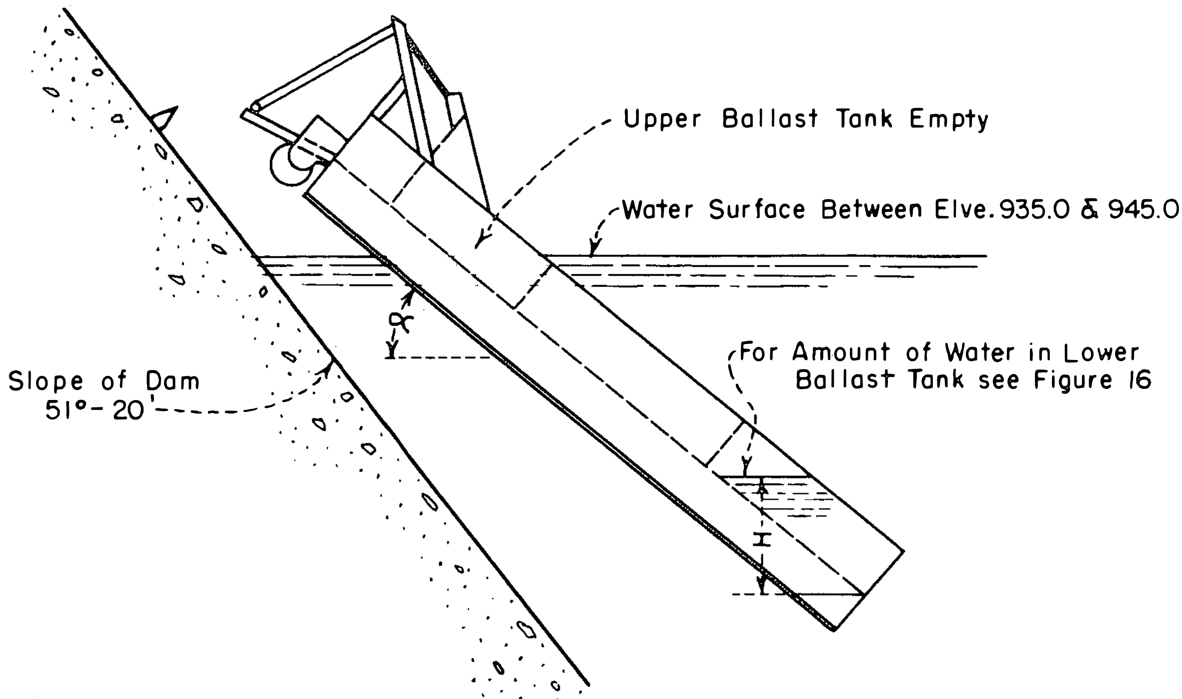


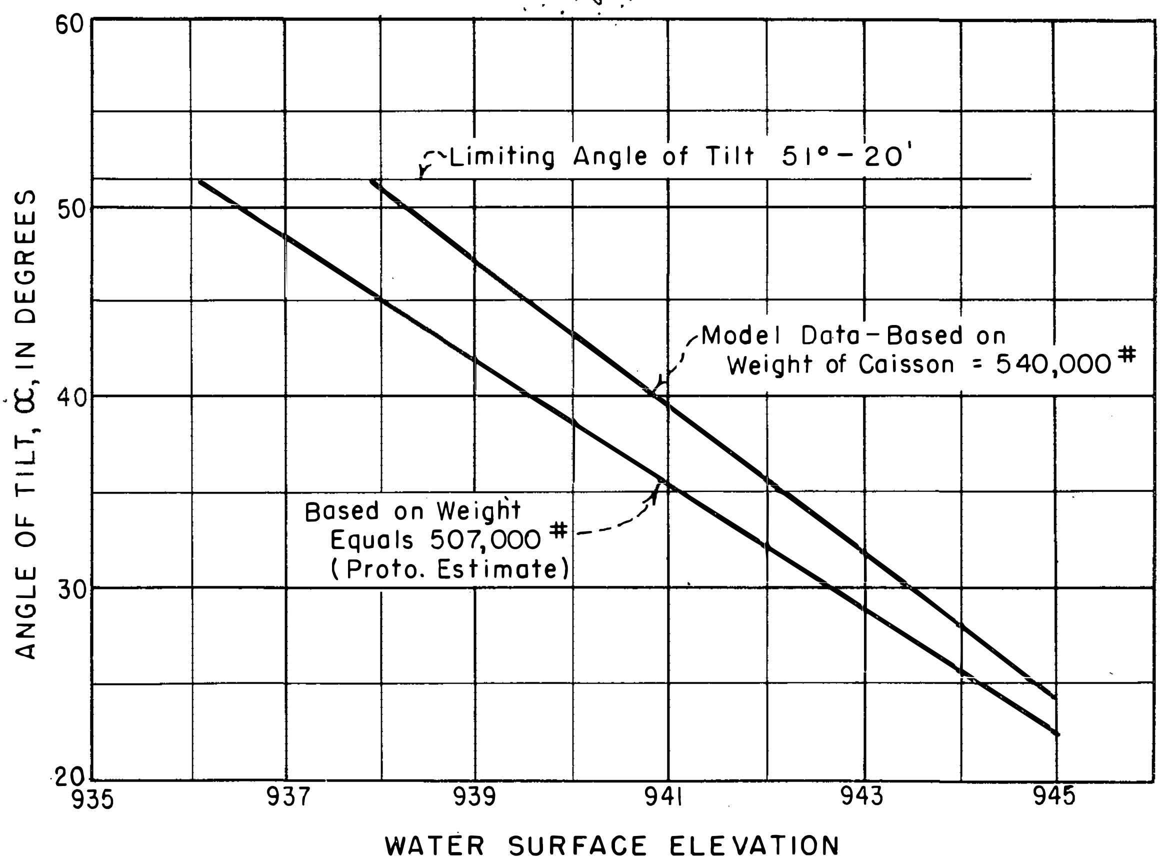
COLUMBIA BASIN PROJECT-WASHINGTON

GRAND COULEE DAM

HYDRAULIC STUDIES ON 1:20 MODEL
OF SPILLWAY FACE CAISSON

RELATION OF TILT TO WATER IN UPPER
AND LOWER BALLAST TANKS





COLUMBIA BASIN PROJECT-WASHINGTON

GRAND COULEE DAM

HYDRAULIC STUDIES ON 1:20 MODEL
OF SPILLWAY FACE CAISSON

TILT ANGLE TO REACH MOORING
POST FOR VARIOUS T. W. ELEVATIONS