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MODEL STUDIES OF SEDIMENT CONTROL STRUCTURES ON DIVERSION DAMS

By

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SYNOPSIS

Diversion of water from streams with alluvial beds into main irrigation canals presents a number of knotty problems for the hydraulic designer. One of the most difficult is that of conducting as much as possible of the stream bed load material through the dam structure, thereby avoiding its expensive removal from the canal.

Resources of the hydraulic laboratory were utilized in developing the designs of several diversion structures to intercept the maximum of bed load carried with water diverted for irrigation purposes. Intermittent sluicing and continuous sluicing methods were investigated, together with various adaptations of the vortex tube and short tunnel. In general for operation at ultimate capacity the most effective diversion method developed is continuous sluicing adjacent to canal headworks in a direction approximately 60^{o} to direction of diversion. Where stream velocities are adequate, curved guide walls leading to headworks and sluiceways greatly increase the efficacy of the general sediment exclusion plan. For smaller diversion structures a modified vortex tube was found to be highly effective.

INTRODUCTION

Control and removal of coarse sediment carried into canals by water diverted from heavy sediment-laden streams is an important part of design and the operation of many present-day irrigation projects. With the increasing demand for water and greater diversions from these streams, the importance of the problem of excluding sediment from the canals will continue to increase.

On some of the larger projects, elaborate desilting works have been built such as that on the All-American Canal which utilizes settling basins and clarifier scrapers. On the smaller projects, however, the cost of such structures cannot be justified, and simpler and cheaper

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means are required. The use of sluiceways to control sediment at diversion weirs by wasting part of the water has been used in many instances. Some of these structures have proven satisfactory, but many have failed to exclude the coarse sediment from the canal systems and frequent dredging of the canals has been necessary.

The design of headworks and sluiceway structures for controlling sediment at river diversions has been carried on for many years in India, Pakistan, and other countries. The design of this type of structure is a comparatively new process in the United States, particularly for projects in which a large percentage of the river flow is diverted for irrigation use. The cost of sediment removal from canals is one of the largest items in connection with the operation and maintenance of irrigation projects. For example, the cost of cleaning sediment from canals on the Rio Grande Project has been as high as $400 per mile in 1946 and $335 per mile in 1947 where various kinds of mechanical equipment were employed. Thus, it is evident that the most effective methods of excluding sediment from canals at headworks reduce the cost of cleaning. Model studies made at the Hydraulic Laboratory of the Bureau of Reclamation have developed effective methods of limiting the amount of coarse sediment entering canal headworks at diversion dams for specific projects.

The testing box built in the Hydraulic Laboratory for Superior-Courtland model studies has been used as a general testing facility for model studies of various diversion dams. Each diversion dam with its individual design requirements and field conditions requires separate studies to give the most satisfactory solution. A design study begins with a preliminary design which is modeled in the laboratory. The laboratory engineer in close liaison with the designers develops the solution to give the best sediment control. All of the model studies reported herein were conducted to give qualitative rather than quantitative information.

SUPERIOR-COURTLAND DIVERSION DAM, CANAL HEADWORKS AND SLUICEWAY STRUCTURES

A model study of this diversion works was made in 1948 and 1949. The primary purpose of the study was to develop the headworks design that would cause the highest percentage of bed load to be carried through the sluiceway. The index used to indicate the performance effectiveness was the ratio of the concentration of the sand in the water passing through the sluiceway to concentration of sand in the water passing through the headworks, $\frac{C_s}{C_h}$. Since it was necessary to obtain good movement of the sand used in the bed with relatively small discharges, as large a model as possible was deemed necessary to obtain satisfactory results. With the space available in the laboratory, it was found that a 1:15 undistorted model could be used which would include an area sufficient to cover one-half of the diversion weir, the Courtland Canal headworks and sluiceway, and approximately 400 feet of the upstream river channel. The general layout of the diversion dam is shown in Figure 1.

Although the model was built to an undistorted scale, it was realized that in order to get sufficient movement of sand through the model, either the discharge or the slope scale would have to be increased. The discharge was set according to the Froude similitude requirements and the slope was allowed to build up to that required to move the sand fed into the model. This caused a slope greater than that derived from the Froude similitude relationship for an equilibrium sediment transportation condition. Following precedent of movable bed model studies, the main requirement was that the bed material would move readily with the discharge and velocities obtained in the model.

It is of interest that the average slope of the river bed in the vicinity of the Superior-Courtland Diversion site prior to construction was approximately 0.00076, and that the slope of the river approach in the model when equilibrium sediment transportation conditions were reached was approximately 0.0076. The sand used for the movable bed material was obtained from a loosely cemented sandstone broken down in a hammer mill, giving a sand with a median diameter of approximately 0.2 millimeter with 90 percent retained between the No. 40 and No. 100 US standard screens (0.42 millimeter to 0.15 millimeter). Figure 2 shows photomicrographs of the model sand and the washed Republican River sand. Size comparisons can be made from the 1 millimeter rectangular grid shown on the photomicrographs.

The ratio of settling velocities of model and prototype sediments is used by many experimenters of movable bed models as the criteria in choosing the model sediment. In the Superior-Courtland model studies, the main requirement for the model sediment was that it would move similar to the bed sediment of the prototype with the discharge and velocities obtained in the model. This requirement was satisfied by the sediment described previously. As a matter of interest, a graph showing a comparison of the settling velocities of the model sediment and the prototype bed sediment according to the Froude velocity scale ratio for the model is shown in Figure 3. The velocity ratio varies as the length ratio to the one-half power, $L_R^{1/2}$.

A 10-year operation study which included the river flow, storage capacity, and diversions of the Republican River drainage area was made on the basis of complete development of the proposed irrigation systems. The operation study gave the monthly average discharge through the headworks and sluiceway of Courtland Diversion. From this analysis, a standard discharge of 600 cfs for Courtland headworks and sluiceway with 400 cfs going through the headworks and 200 cfs through the sluiceway was chosen for the model study. The design capacity of Courtland Canal is 751 cfs. However, this maximum discharge occurs over very short periods.

Studies of the only sediment data available at the time, on the Republican River near Bloomington, Nebraska, 80 miles upstream from the dam site, indicated that the bed load amounted to 0.165 percent of the water discharge by weight. For the standard river discharge chosen for the model study, 600 cfs, the bed sediment load amounted to approximately 1-1/4 acre feet per day. In model terms the sand feed amounted to 0.0173 pound per second for the same sediment concentration as the prototype.

The channel used as a feeding trough had a capacity of 25 pounds of dry model sand. The rate of sand feed used was one channel full each 5 minutes which gave a sediment concentration slightly higher than the prototype sediment concentration. The sand was dumped from the feeding trough on to a broad crested weir, and was washed into the model by the water flowing over the weir.

Samples of water and sand flowing through the headworks and sluiceway were taken at regular intervals by passing a collecting trough across the width of the falling nappes at the end of the headworks and sluiceway. The samples passed through closed pipes to tanks graduated to read the volume of water. The sand settled into glass funnels fastened to the bottoms of the tanks by removable rings. The glass funnels, graduated to read weight of sand direct, could easily be removed and the sand washed out after reading. The concentrations by weight of sand to water were quickly determined by this arrangement for both headworks and sluiceway and the concentration ratios easily computed. Concentrations of individual samples from the headworks and sluiceways varied considerably because of the shifting approach channel. This action is typical of the flow in the Republican River. By taking the time average of concentrations over a comparatively long period, equilibrium sediment transportation conditions could be determined.

Preliminary design--Courtland headworks. An initial test was made with the sluiceway and headworks arranged as shown in Figure 1 without the guide walls. The model was operated until equilibrium sediment transportation conditions were reached. Samples were then taken from the water and sand passing through the headworks and sluiceway. The average of concentrations shown by samples taken at equilibrium conditions gave a ratio of sediment concentration in the sluiceway to the concentration in the headworks, $\frac{C_s}{C_h}$ of 0.682. Normal water surface elevations of 1639.0 feet, 0.5 foot below the spillway crest was maintained for all continuous sluicing tests.

Next, a system of intermittent sluicing was tried. The sluiceway and headworks gates were set to the standard discharge, and the model operated at these conditions for 55 minutes. The sluiceway gate was then opened full for 5 minutes, after which it was reset to the standard opening and operated for an additional 55 minutes. This cycle was repeated each hour for a total run of 20 hours. During the sluicing period, the head pool elevation would drop and heavy scour occurred in front of the headworks with the riprap floor at elevation 1632, being exposed over most of the area. A pronounced channel was scoured upstream through the head pool deposit.

The samples taken between sluicing periods gave a ratio of $\frac{C_s}{C_h} = 0.713$, and the samples taken during the sluicing periods gave a ratio of $\frac{C_s}{C_h} = 4.269$. Although this system of operation appeared to offer a great deal of promise as far as efficient removal of sand was concerned, it was recognized that the fluctuation of the canal water level due to varying the discharge through the headworks during the cycle would cause sloughing of canal banks constructed in sandy material and was, therefore, not a satisfactory means of operation on the Superior-Courtland Canals. Intermittent sluicing has been used successfully where the canal banks can withstand comparatively rapid water level fluctuations without sloughing.

Several guide wall and skimming weir arrangements were studied in the model. Each of these arrangements is shown in Figure 4. Table 1 shows the results of the tests giving a concentration ratio of $\frac{C_s}{C_h}$ for each[1] arrangement tested. Changes 1, 2, and 3 include walls which were all attached to the headworks of the upstream part of the structure, and they gave results which were not as good as the preliminary design.

A guide wall extending upstream from a point between the sluiceway and the overflow weir was installed to a predetermined curve. The guide wall curved the flow, inducing a secondary current which caused the bed material to move toward the inside of the curve. Change 4, Figure 4, shows this curved guide wall arrangement. A ratio of sediment concentration $\frac{C_s}{C_h}$ for this curved guide wall arrangement was 6.629.

Most of the previous tests indicated that the guide wall, as used in Change No. 4, was the most satisfactory in the solution of the problem. From observations made on a number of tests, it appeared necessary to make the channel between the guide wall and the headworks as narrow as possible. Curving the flow with a guide wall caused a secondary current to move the bed materal to the inside of the curve only when there was enough excess head on the outside of the curve, due to centrifugal force, to activate a strong secondary current. Therefore, it was desirable to have as high a velocity as possible without picking up an excess amount of bed material into suspension. With normal canal depth maintained below the headworks, the width of the approach channel was determined for maximum diversion requirements.

For diversions less than the canal design capacity 751 cfs, it was possible to operate the headworks with part or all of the gates partially open. The model tests were made with all five headworks gates opened equally until the best approach arrangement was determined and then tests were made in which gate openings for the five head gates were varied to effect a nonuniform velocity distribution in the headworks approach. Several combinations of gate openings for the head gates were tried but the tests with uniform gate settings gave the minimum sediment entering the canal.

Table 1

DESIGNS TESTED--COURTLAND HEADWORKS AND SLUICEWAY

Change Number	Length of test hours	Q_s cfs	Q_h cfs	C_s ppm	C_h ppm	C_s/C_h	Remarks
Preliminary design	27	200	400	1,074	1,574	0.68	See Figure 4
Preliminary design	15	400	200	1,295	977	1.33	
Preliminary design	20	200	variable	30,058	7,041	4.27	During sluicing period of intermittent sluicing run
Preliminary design	20	200	400	74	104	0.71	Between sluicing periods of intermittent sluicing run
1	21	200	400	457	2,116	.22	Skimming weir upstream of headworks
2		200	400				Observations showed this design not satisfactory--No data taken--See Figure 4
3		200	400				Observations showed this design not satisfactory--No data taken--See Figure 4
4	15	200	400	3,149	475	6.63	Curved guide wall with curved embankment
5		200	400				Observations showed this design not satisfactory--No data taken
6	20	200	400	2,508	489	5.13	Straight embankment at 60° angle--head gates opened uniform
7	31	200	400	3,785	361	10.5	Vortex tube installed--sluice gate 10 feet wide

DESCRIPTION OF HEADINGS

Q_s = Average discharge through sluiceway cfs (prototype)
Q_h = Average discharge through headworks cfs (prototype)
C_s = Average sediment concentration in sluiceway ppm by weight
C_h = Average sediment concentration in headworks ppm by weight

Table 1 (continued)

DATA FOR DESIGNS TESTED--SUPERIOR HEADWORKS AND SLUICEWAY

Change Number	Length of test hours	Q_s cfs	Q_h cfs	C_s ppm	C_h ppm	C_s/C_h	Remarks
Preliminary design	54	40	80	37	2,669	.014	See Figure 5
1	23	40	80	311	1,707	.18	Guide wall installed. Original embankment
2	39	40	80	1,247	1,950	.64	Guide wall with straight embankment. Recommended design

DESCRIPTION OF HEADINGS

Q_s = Average discharge through sluiceway cfs (prototype)
Q_h = Average discharge through headworks cfs (prototype)
C_s = Average sediment concentration in sluiceway ppm by weight
C_h = Average sediment concentration in headworks ppm by weight

The arrangement shown as Change No. 7 in Figure 4 included a vortex tube extending across the face of the headworks immediately upstream from the headworks sill. A closed conduit on the end of the vortex tube discharged into the sluiceway downstream from the sluice gate. A complete run with this arrangement at the standard water discharge and sediment feed and uniform gate settings showed a $\frac{C_s}{C_h}$ ratio of 7.5. A test was then made in which the sluice gate was reduced from 20 to 10 feet in width. This arrangement gave even a more satisfactory ratio of $\frac{C_s}{C_h}$ of 10.5. These last runs indicated that the vortex tube and the narrow sluice gate improved the sand distribution considerably. However, due to the necessity of passing floating debris and other design considerations, these two features could not be incorporated into the Superior-Courtland design.

Superior headworks. The Superior headworks and sluiceway is on the opposite end of the diversion dam from the Courtland Canal. To test the Superior headworks and sluiceway it was necessary, in effect, to reverse the model in plan. The model of Courtland headworks was then modified to represent Superior headworks by blocking out four of the five head gates and changing the alinement of the upstream river bank. The preliminary design of Superior headworks and sluiceway was tested using 120 cfs as a total standard discharge, with 80 cfs being passed through the headworks and 40 cfs discharged through the sluiceway. These discharges were chosen from data compiled in the 10-year operation study for the Republican River drainage discussed in the Courtland model studies. Tests on a preliminary design of Superior headworks and sluiceway gave a concentration ratio $\frac{C_s}{C_h}$ of 0.014.

In view of the fact that the design was so far advanced, it was impracticable to alter the structures of the headworks and sluiceway very markedly. The recommended design for Superior headworks and sluiceway is shown as Change 2 on Figure 5. The best sediment concentration ratio obtainable with the arrangement described above was $\frac{C_s}{C_h} = 0.64$. This shows that considerable coarse sediment was still going into the headworks, but it was a great improvement over the preliminary design. It will be noticed that a much higher concentration ratio $\frac{C_s}{C_h}$ was obtained in the model study for Courtland headworks and sluiceway than for Superior model headworks and sluiceway. On the Superior study it was necessary to keep the opening between the guide wall and the river embankment equal to or greater than 20 feet, which was arbitrarily chosen at the time as the minimum for passing floating debris. Meeting this requirement necessitated lower velocities around the curved entrance channel and thereby reduced the effectiveness of the secondary current to move bed sediment to the inside of the curved channel.

In recommending these designs, it is stressed that the best final operating conditions and gate settings should be determined in the field. In most of the model tests, the ratios between canal and sluiceway discharges were maintained constant for both diversions. In actual operation, the available sluicing water should be apportioned between the Courtland and Superior sluiceways in relation to the amounts of sediment being carried into the canals rather than by water discharges. During the early years of the project when low discharges will be diverted into the canals, it may be possible to use intermittent sluicing without a dangerous water level fluctuation in the canals. Greater quantities of sediment can be kept out of the canals by this method of operation when discharges are comparatively low.

REPUBLIC DIVERSION DAM, HEADWORKS AND SLUICEWAY STRUCTURES

Upon the completion of the Superior-Courtland model tests the existing model was modified to represent the Republic Diversion Dam headworks and sluiceway. Inasmuch as the model scale was the same, 1:15, it required only a slight change in the upstream layout and the installation of a new headworks structure. The overflow weir and sluiceway were left unchanged with the exception of relocating the sluiceway gate. The general layout of the diversion dam is similar to that for Superior-Courtland and is shown in Figure 6.

The sand used for the movable bed was the same as used for the Superior-Courtland tests. Two electrically activated pan feeders were mounted over the head end of the model to give a uniform sand feed at a rate of approximately 1/4 pound per minute, the computed bed sediment discharge for equal sediment concentrations in the model and prototype. The feeders received sediment from hoppers and were controlled by means of rheostats. This uniform continuous method of feeding the sand was a great improvement over the method used on Superior-Courtland model in which a given weight of sand was added at 5-minute intervals.

Samples of the water and sediment flowing through the sluiceway and headworks were taken at regular intervals by passing a collecting trough through the falling nappes. The samples were collected in tanks, calibrated to read volume of water in liters and the amount of sand in grams (dry weight). All concentrations are in parts per million dry weight.

A standard discharge of 180 cfs divided so 120 cfs passed through the headworks and 60 cfs passed through the sluiceway was used for all runs. It will be noted that this discharge is about one-third the discharge used in the model studies of Courtland headworks, but it was a little higher than the discharge used for Superior model headworks.

Preliminary design. The initial tests were made with the headworks and sluiceway arranged according to preliminary designs as shown in Figure 6. Wide variations in concentrations of sediment in both headworks and sluiceway were caused by the frequent shifting of the approach channel upstream from the headworks and the movement of bed sediment in waves or dunes. The average concentration ratio for a comparatively long test, 109 hours, gave $\frac{C_s}{C_h} = 1.26$. All tests of changes from the preliminary design were compared to this ratio.

Several arrangements were tested in which two curved guide walls confined the flow as it approached the headworks and sluiceway. Both a 20-foot and a 10-foot channel with average radii of curvature varying from 47.2 feet to 90.5 feet were tested. These arrangements are shown on Figure 7 as Changes 2, 3, and 4. The concentration ratios $\frac{C_s}{C_h}$ for these three changes are lower than the concentration ratio for the preliminary design. The reason for the lower concentration ratios was the comparatively small discharge and consequently the low velocities. Compared to the average velocities obtained in the Courtland headworks model, the average velocities in the approach channel between the guide walls of Republic headworks was only approximately one-third for similar arrangements. A similar comparison was noted on the velocities in the approach channel between Superior and Courtland model tests.

Tests utilizing a vortex tube. In Change 5, Figure 7, is shown the layout of the Republic headworks model with a 12- by 15-inch elliptical vortex tube installed upstream of the headworks gate. Tests on a larger model and tests by other investigators have shown the vortex tube to work more efficiently when the tube is at an angle with the line of flow.[3]

[3]Ralph L. Parshall, "Model and Prototype Studies of Sand Traps," ASCE Transactions Vol. 117, 1952, pp. 204-214.

For this reason the next run was made with the vortex tube installed at an angle of 65° with the line of flow. The tests with a 65° vortex tube with no guide wall gave a concentration ratio of $\frac{C_s}{C_h}$ of 1.34.

To further increase the sediment removal with the vortex tube, a horizontal vane tapered on the under side upstream and downstream from the axis of the tube was installed over the vortex tube. A sketch of this design is shown on Figure 7. The tapered vane increased the velocity directly over the tube causing the vortex in the tube to be much stronger and to move the sand out the exit. The Republic headworks model was tested with the horizontal vane 0.625, 1.25, and 1.875 feet above the sill of the headworks. The best sediment concentration ratios were obtained with the vane 1.25 feet above the sill of the headworks, as indicated in Table 2.

Table 2

DESIGNS TESTED--REPUBLIC DIVERSION

Change Number	Length of test hours	Q_s cfs	Q_h cfs	C_s ppm	C_h ppm	C_s/C_h	Remarks
Preliminary design	81	60	120	2,279	1,811	1.26	
1	32	60	120	1,721	654	2.63	
2	30	60	120	1,108	1,792	0.62	20-foot wide guide channel
3	34	60	120	1,432	1,479	.97	10-foot wide guide channel
4		60	120				Observations made--No data taken
5	27	60	120	726	316	2.30	Vortex tube installed with vane 1.25 feet above tube--Guide walls installed
6	24	60	120	821	445	1.84	Vortex tube installed with vane 1.25 feet above tube--Sloping floor entrance--No guide walls

DESCRIPTION OF HEADINGS

Q_s = Average discharge through sluiceway cfs (prototype)
Q_h = Average discharge through headworks cfs (prototype)
C_s = Average sediment concentration in sluiceway ppm by weight
C_h = Average sediment concentration in headworks ppm by weight

Another improvement was obtained by installing a sloping floor upstream from the headworks to make the entrance more streamlined and reduce the turbulence. This reduced the amount of sediment in suspension and consequently increased the percentage of sediment moving near the bed and into the vortex tube. The concentration ratio $\frac{C_s}{C_h}$ with the sloping apron installed, the vortex tube installed at 90° with direction of flow, and the guide walls removed, was 1.85.

The arrangement which gave the best sediment control included a vortex tube set in the headworks floor upstream from the gate at an angle of 65° with the direction of flow. The tapered vane was set at 1.25 feet above the headworks floor. The concentration ratio $\frac{C_s}{C_h}$ for this arrangement was 2.30.

The inclusion of a vortex tube in the model gave the greatest improvement of any individual change. Although the sediment in the bed of the Republican River is comparatively fine, the velocities of approach to the headworks are slow enough that a large percentage of sediment moves close to the floor. The vortex tube was first developed by Mr. Ralph L. Parshall.[3] However, as far as is known, use of a horizontal tapered vane to increase the efficiency of the vortex tube has never been made before. Final design of Republic Diversion Dam has been delayed and consequently the selection of sediment control arrangement has not been made.

MODEL STUDIES OF BARTLEY DIVERSION DAM HEADWORKS AND SLUICEWAY

Continuing the sediment control studies at headworks of diversion dams, a 1:7 scale model of the headworks and sluiceway of Bartley Diversion Dam was constructed and tested. The dam is also located in Nebraska on the Republican River well upstream from Superior Courtland and Republic Diversion Dams. The Bartley Diversion Dam will consist of two compacted earth dikes approximately 2,100 feet long and 18 feet high, a 700-foot wide overflow spillway, two 10-foot wide sluiceways, and a 20-foot wide headworks structure leading to Bartley Canal. The plan of the dam is shown in Figure 8. A limited time was allowed for the model study and, therefore, the scope of the study was limited. However, by taking advantage of the previous studies, a good sluicing action was obtained. A preliminary layout of the model is similar to Republic Diversion Dam. The fine sand used as the movable bed material in Superior-Courtland and Republic Diversion Dam studies, previously described, was also used for the Bartley model studies. A comparison of the size analysis of the model and prototype bed material based on the settling velocities for the scale ratio of 1:7 is shown on Figure 9.

Operation of the model. From a hydrological study, it was shown that 60 cfs would be required in the Bartley Canal approximately 78 percent of the time, and that 37.5 cfs would be available for sluicing approximately 70 percent of the time. These discharges were arbitrarily chosen as standard for the Bartley model studies. This division of flow was varied for some of the tests. From field measurements, it was discovered that the sand bed load concentration in the Republican River at the Bartley site was 474 ppm by weight. This same concentration was used in the model study. The sand and water discharges were held constant throughout the studies. Like the previously described studies, it was found that the sediment concentrations passing through the headworks and sluiceway varied with time because of the continually shifting channel of the upstream river bed and because the sediment approached the headworks and sluiceway in waves along the bed. To take into consideration this fluctuation, samples of the discharges through the headworks and sluiceway were taken simultaneously and at varying intervals throughout the tests. By averaging the concentrations, a time average for each test was obtained.

The preliminary design was tested in the model and a concentration ratio of $\frac{C_s}{C_h} = 0.13$ was obtained by sampling. This shows that the largest portion of the bed sediment was being taken into the headworks. Four changes, in which curved guide walls were installed upstream from the headworks and sluiceway in addition to the preliminary design, were tested in the model. Two more changes, including tunnel entrances to the sluiceway between the guide walls, were tested. Table 3 gives a tabulation of all tests showing the concentration ratio $\frac{C_s}{C_h}$ for each arrangement tested. It will be noted that Change 4 has a concentration ratio $\frac{C_s}{C_h}$ of 6.69, and this is the highest ratio of any arrangement in which only the guide walls were added to the preliminary design. Change 5 which includes a tunnel entrance to the sluiceway has a higher concentration ratio than Change 4. However, because of the possibility of collecting trash on the tunnel entrance and the increased cost of the tunnel over the guide walls alone, Change 4 was recommended for inclusion in the prototype design. A sketch of all the changes tested in the model, as well as the recommended design, are shown on Figure 10. The results of Bartley model tests show the improvement in sediment distribution by using the curved stream flow principle to cause the bed load to move to the inside of the curve. The sediment was moved toward the sluiceway and excluded from the headworks. The difference in elevation between the headworks crest and the sluiceway crest of 2.3 feet, the headworks crest being higher, was of definite advantage in keeping the sediment out of the headworks.

Table 3

DESIGNS TESTED--BARTLEY DIVERSION DAM

Change Number	Length of test hours	Q_s cfs	Q_h cfs	C_s ppm by wt	C_h ppm by wt	C_i ppm by wt	C_t ppm by wt	C_s/C_h
Preliminary design	84	37.3	60.2	135	1,020	474	668	0.13
1	51-1/2	39.5	58.0	250	603	474	463	0.41
2	34	37.8	59.7	588	367	474	455	1.60
3	24	38.7	58.8	622	389	474	481	1.60
4	49	38.8	58.7	830	124	474	405	6.69
5	6-1/2	39.5	58.0	901	115	474	427	7.83
6	24	39.0	58.5	808	168	474	423	4.81

DESCRIPTION OF TERMS

Q_s = Average discharge through sluiceway cfs (prototype)
Q_h = Average discharge through headworks cfs (prototype)
C_s = Average sediment concentration in sluiceway ppm by weight
C_h = Average sediment concentration in headworks ppm by weight
C_i = Concentration of sediment added to model ppm by weight
C_t = Average concentration of sediment discharged from model ppm by weight

CONCLUSIONS

The model studies reported herein have shown that the percentage of coarse sediment entering the canal at diversion headworks can be controlled to a significant extent by arranging the entrance to give favorable flow conditions. Guide walls which confine and guide the flow around a curve take advantage of the secondary currents to move the bed sediment to the inside of the curve and toward the sluiceway. To actuate a secondary current it is necessary to have a higher water surface on the outside of the curve than on the inside. This superelevation is a result of centrifugal force on the water moving in the curved path it is forced to take. The model showed that the ideal situation is to have a streamlined entrance condition and an entrance velocity high enough to cause a good secondary current around the curve but not so high as to cause an excessive amount of bed sediment to be picked up into suspension.

Intermittent sluicing can be used successfully where the canal will not be damaged by the water level fluctuations that are characteristic of intermittent sluicing. The vortex tube with a horizontal tapered vane installed in the headworks entrance and a short tunnel separating the top water with smaller sediment concentrations from the bottom water with high sediment concentrations are excellent for keeping bed sediment out of canals especially where there is no floating debris and trash to stop their efficient operation.

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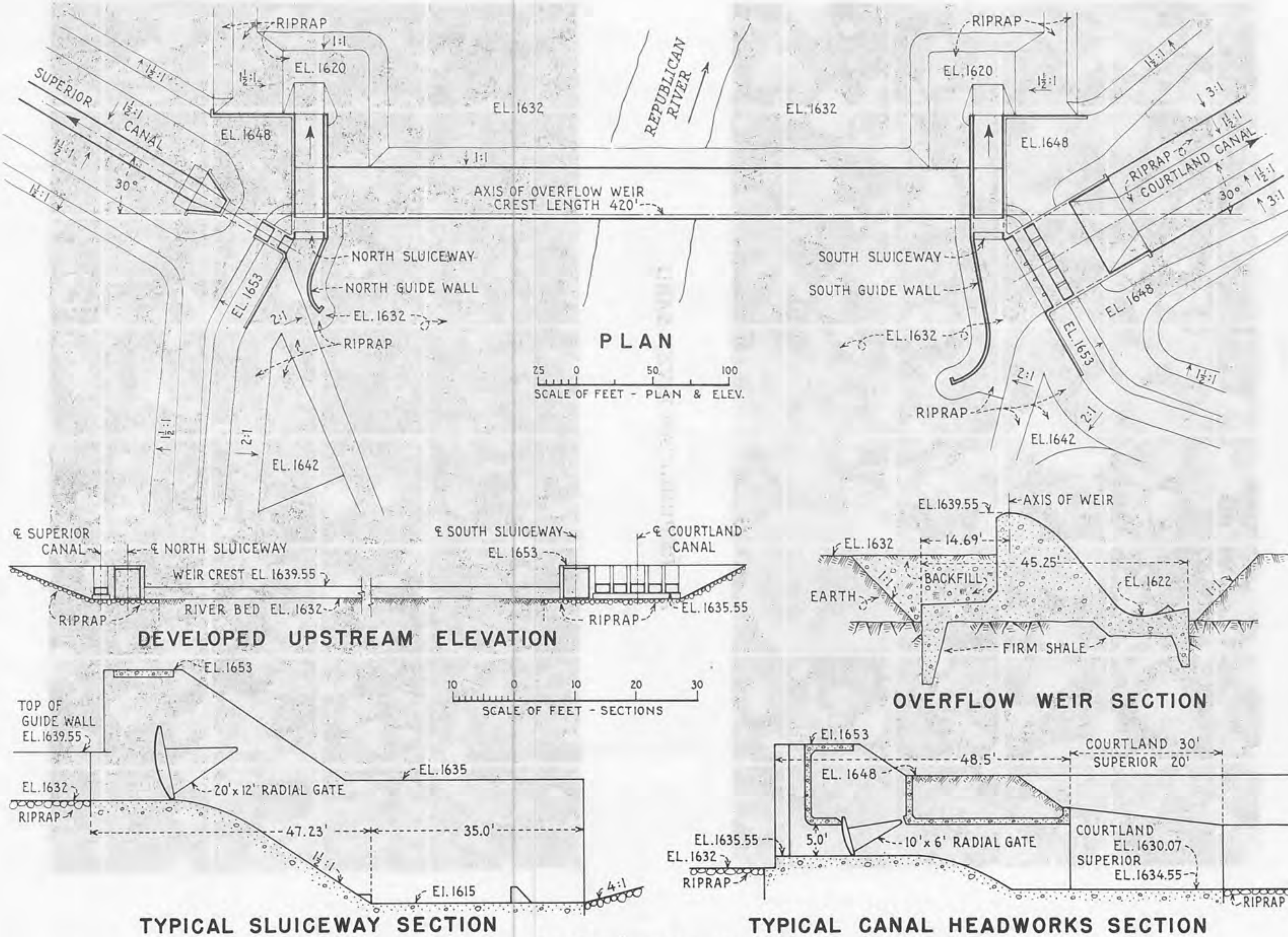
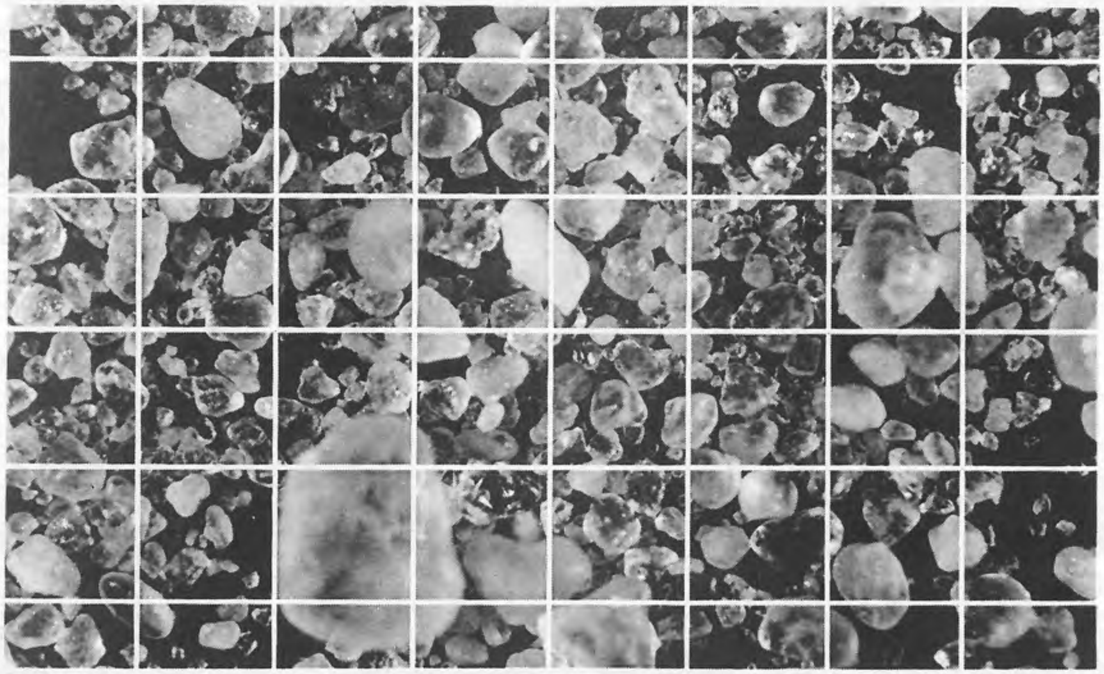


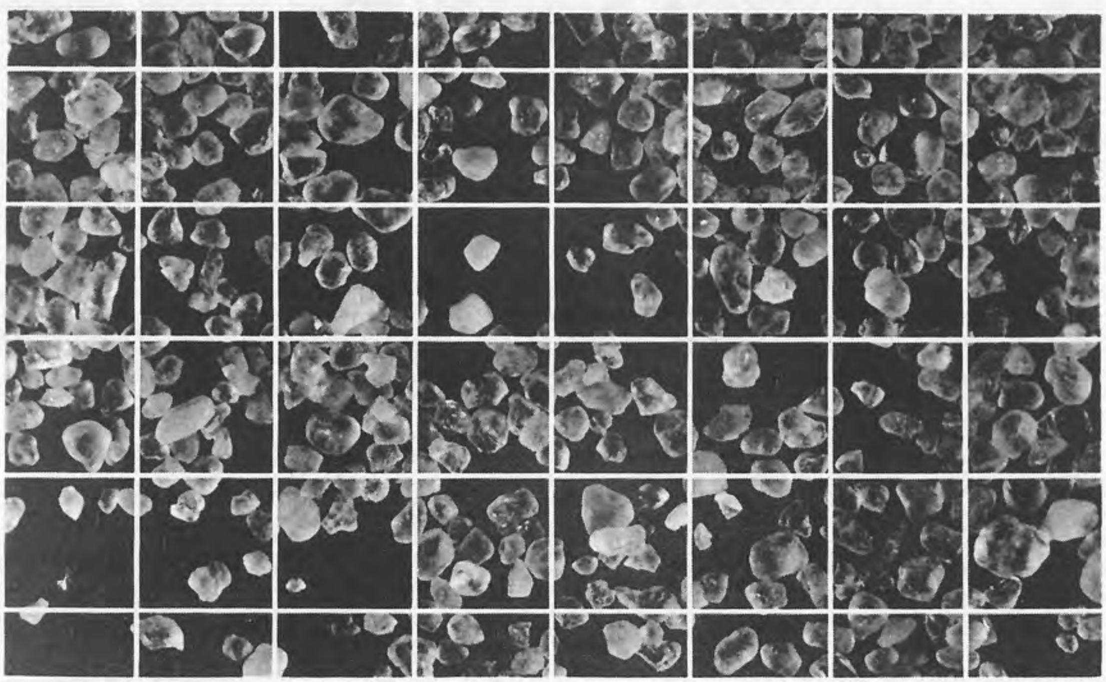
SUPERIOR - COURTLAND DIVERSION DAM

FIGURE 1

Figure 2



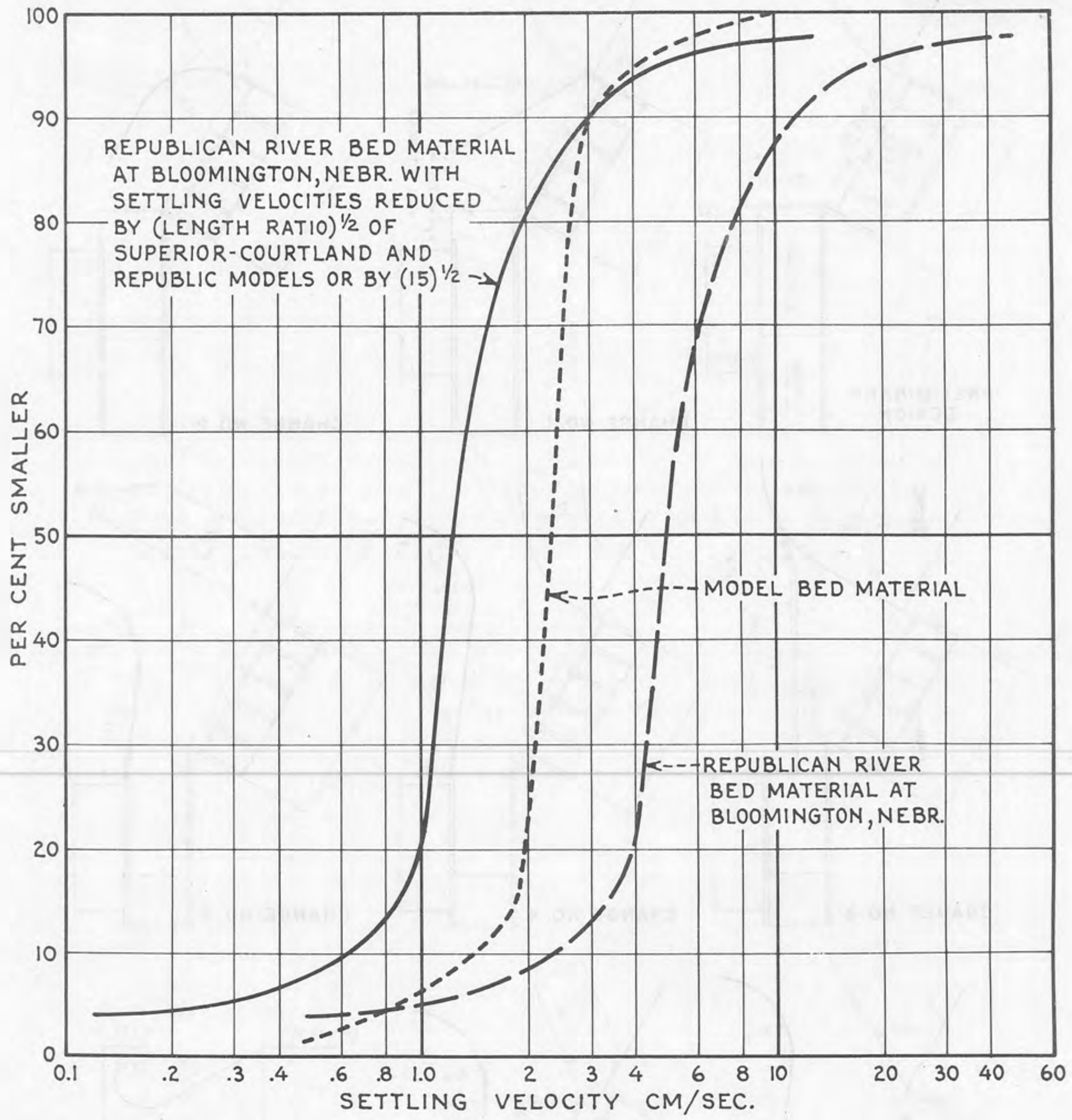
A. REPUBLICAN RIVER SAND



B. MODEL SAND

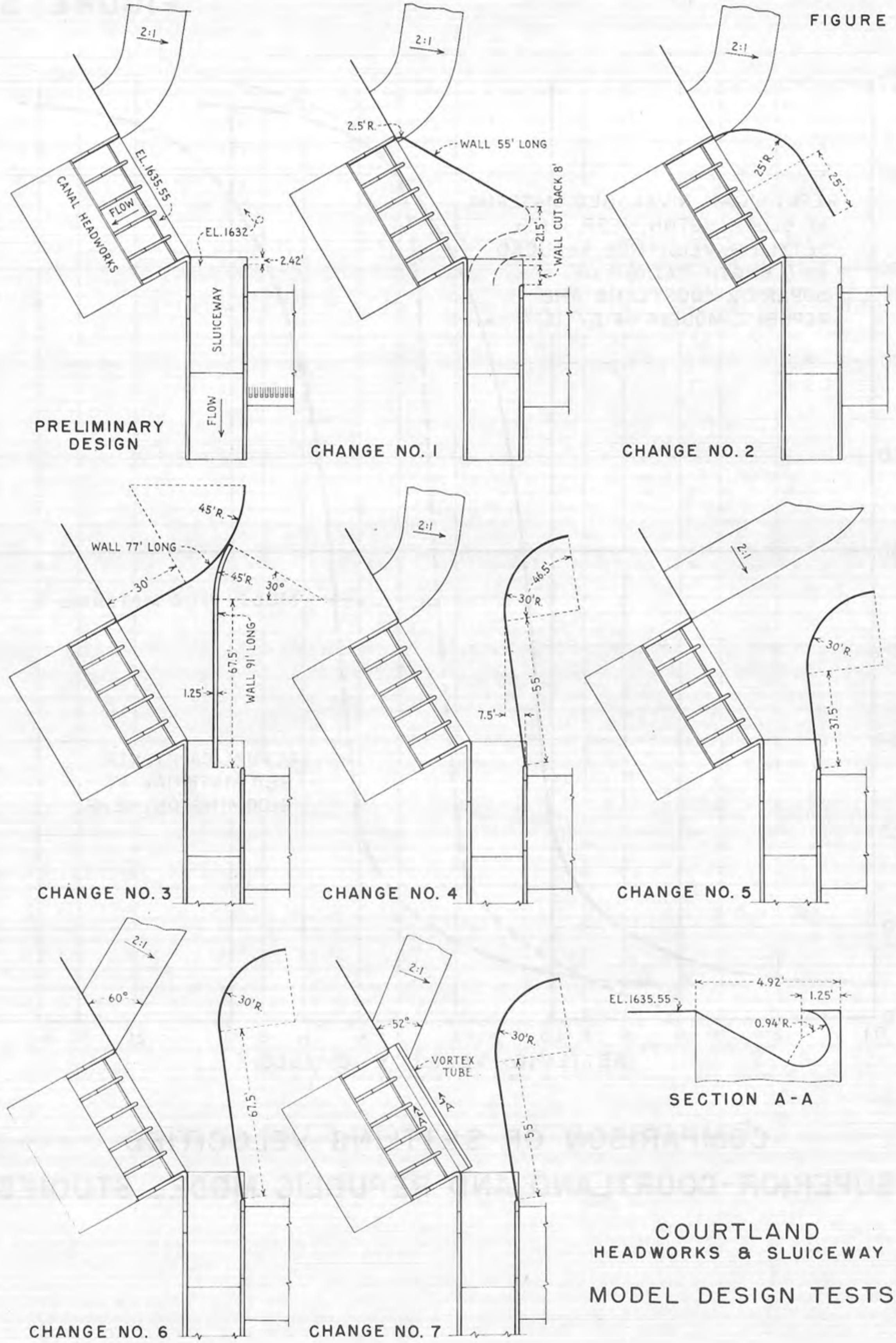
PHOTO MICROGRAPHS OF MODEL AND
REPUBLICAN RIVER BED MATERIALS
GRID SPACING IS 1 mm

FIGURE 3



COMPARISON OF SETTLING VELOCITIES
SUPERIOR-COURTLAND AND REPUBLIC MODEL STUDIES

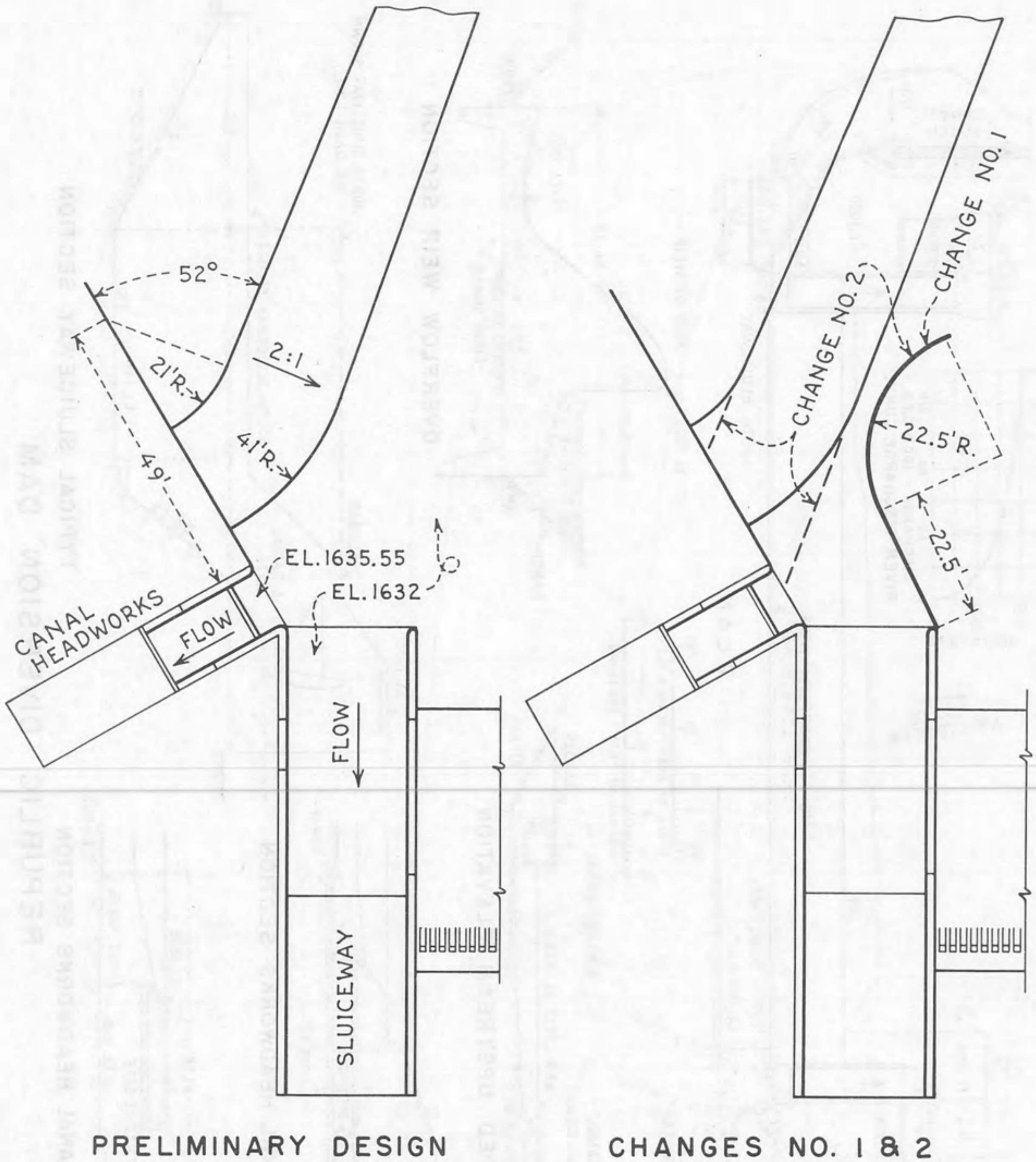
FIGURE 4



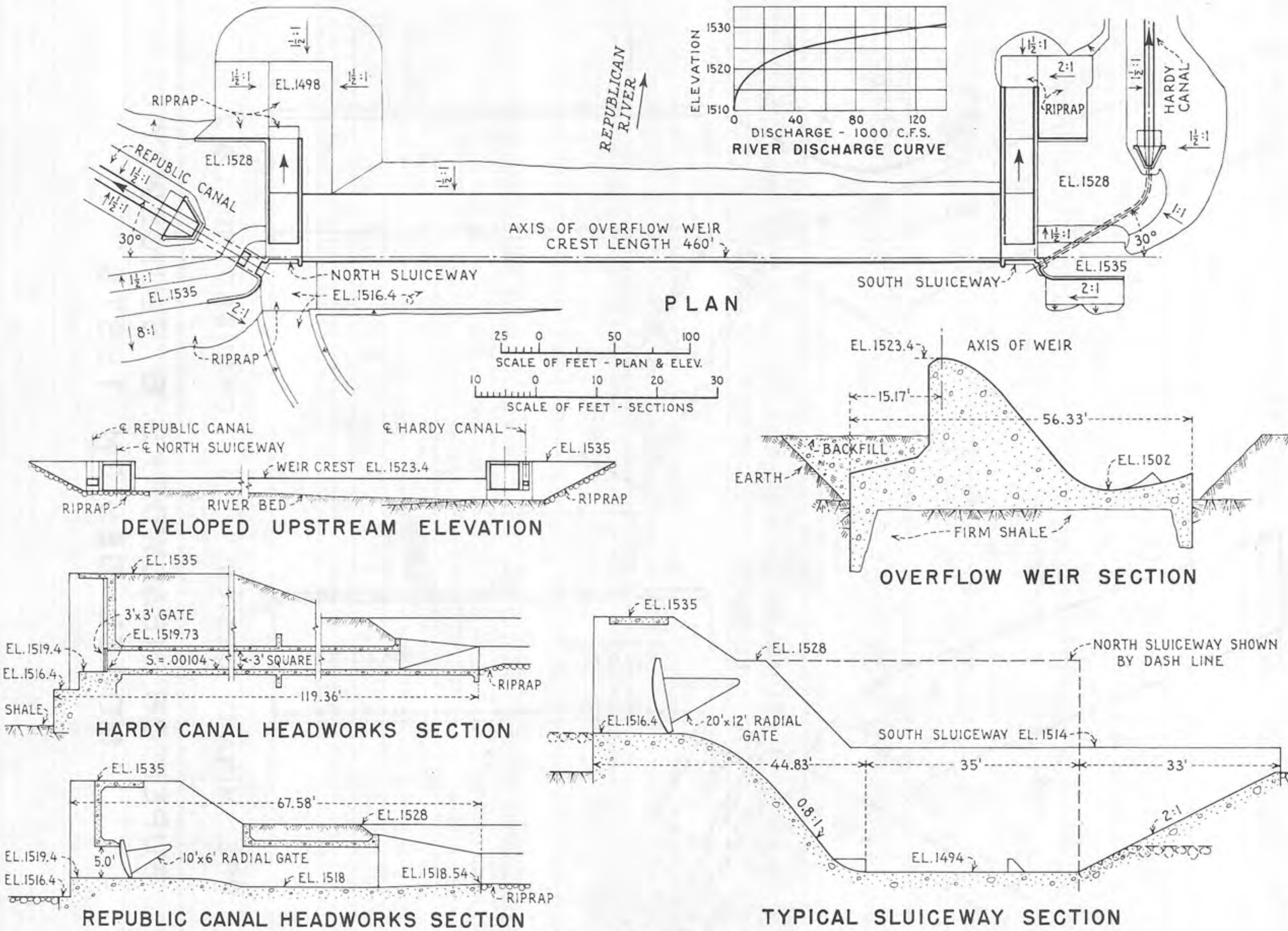
COURTLAND
HEADWORKS & SLUICEWAY

MODEL DESIGN TESTS

FIGURE 5



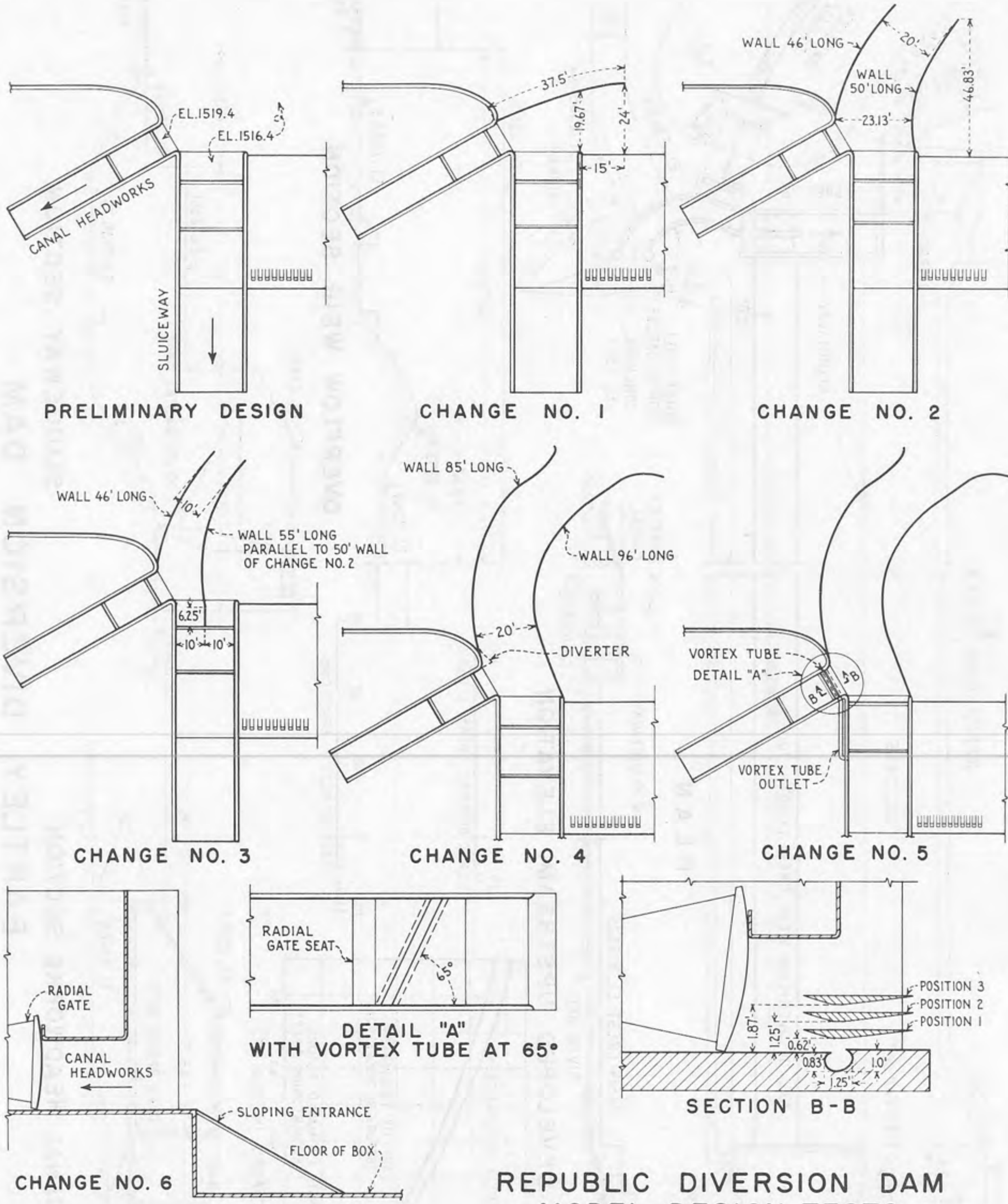
SUPERIOR HEADWORKS & SLUICEWAY
MODEL DESIGN TESTS



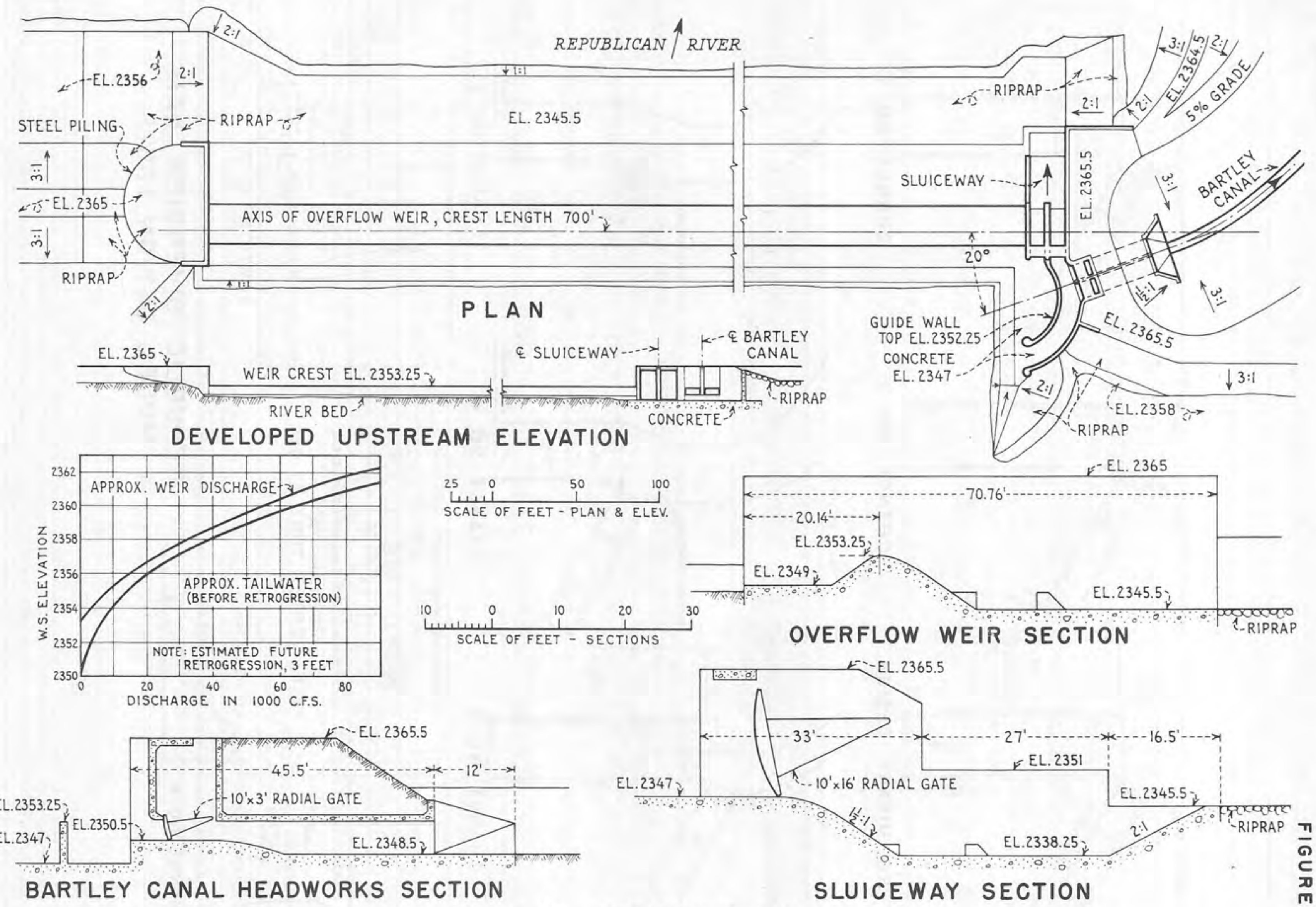
REPUBLIC DIVERSION DAM

FIGURE 6

FIGURE 7



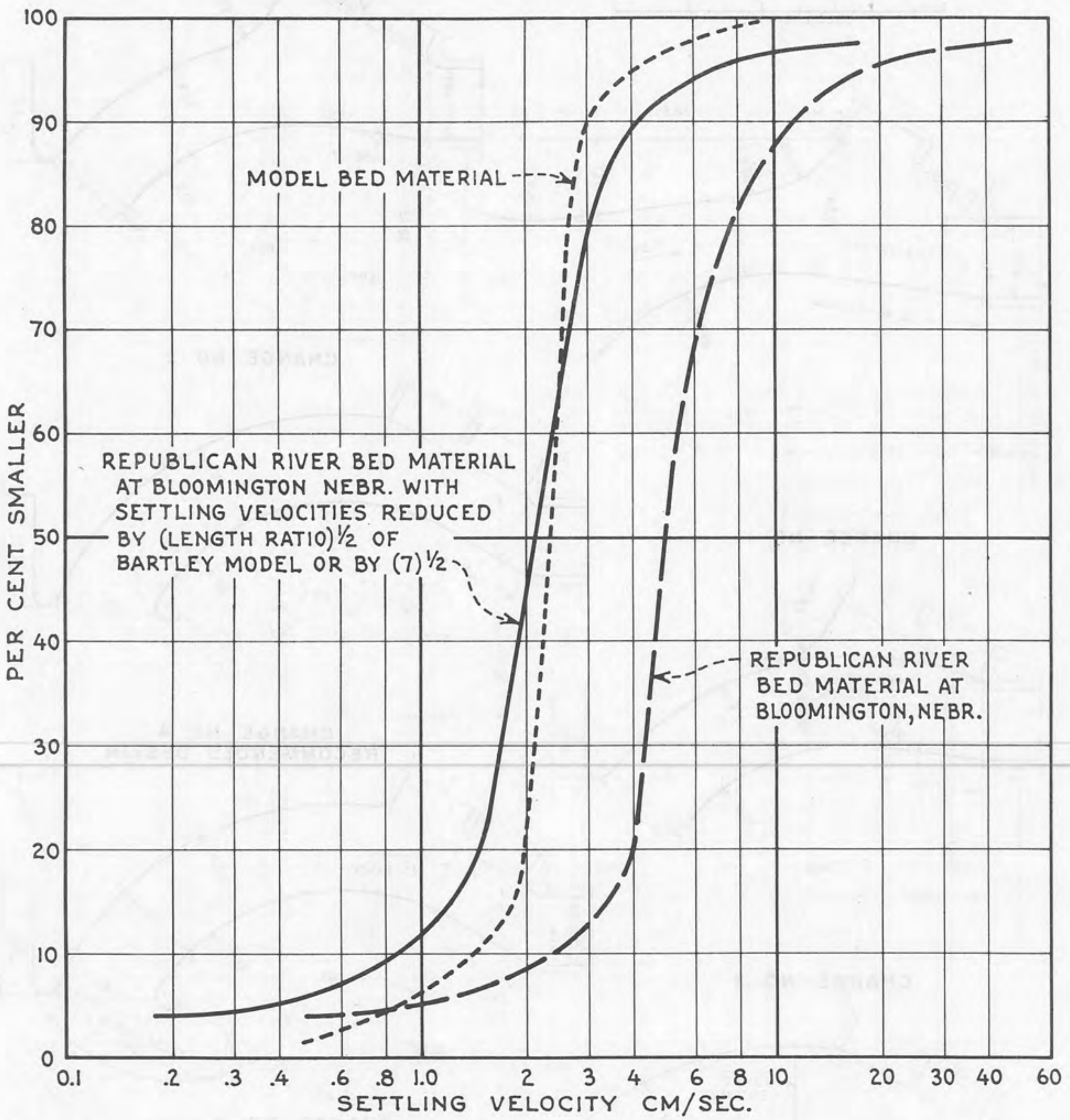
REPUBLIC DIVERSION DAM
MODEL DESIGN TESTS



BARTLEY DIVERSION DAM

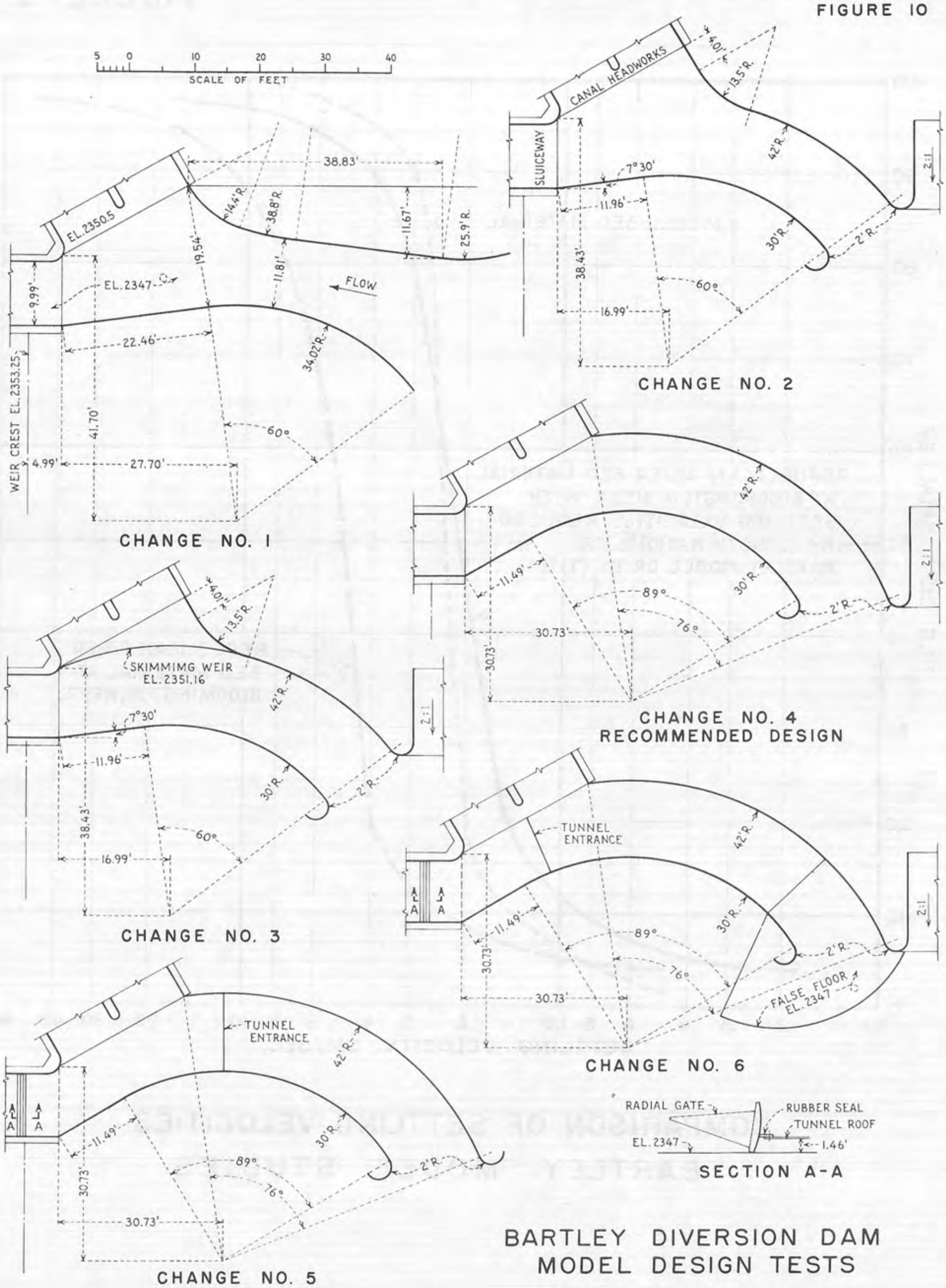
FIGURE 8

FIGURE 9



COMPARISON OF SETTLING VELOCITIES
BARTLEY MODEL STUDIES

FIGURE 10



BARTLEY DIVERSION DAM
MODEL DESIGN TESTS