TECHNICAL REPORT NO. 11

JACKSON HOLE FLOOD CONTROL PROJECT

March 1974

Committee on Channel Stabilization
CORPS OF ENGINEERS, U. S. ARMY

REPORTS OF COMMITTEE ON CHANNEL STABILIZATION

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1	Symposium on Channel Stabilization Problems	
	Volume 1	Sept. 1963
	Volume 2	May 1964
	Volume 3	June 1965
	Volume 4	Feb. 1966
2	Review of Research on Channel Stabilization of the Mississippi River, 1931 – 1962	Sept. 1963
3	Effect of Water Temperature on Discharge and Bed Configuration, Mississippi River at Red River Landing, La.	Aug. 1966
4	Channel Stabilization Publications Available in Corps of Engineers Offices	Nov. 1966
5	A Procedure for Computation of the Total River Sand Discharge and Detailed Distribution, Bed to Surface	Nov. 1968
6	Water-Temperature Effects on Stage-Discharge Relations in Large Alluvial Rivers	Sept. 1969
7	State of Knowledge of Channel Stabilization in Major Alluvial Rivers	Oct. 1969
8	Channel Stabilization, Interoceanic Sea-Level Canal, Lower Atrato River Portion, Route 25, Colombia, South America	Oct. 1969
9	Sedimentation Aspects, Project for Navigation and Flood Control, Lower Colorado River, Texas	May 1972
10	Chena River Lakes Project, Alaska, Problems Relating to Channel Development, Erosion, and Bank and Levee Protection	Mar. 1973
11	Jackson Hole Flood Control Project	Mar. 1974

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ARMY-MRC VICKSBURG, MISS.

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Foreword

Establishment of the Committee on Channel Stabilization in April 1962 was confirmed by Engineer Regulation 15-2-1, dated 1 November 1962. As stated in ER 15-2-1, the objectives of the Committee, with respect to channel stabilization, are:

a. To review and evaluate pertinent information and disseminate the results thereof.

b. To determine the need for and recommend a program of research; and to have advisory technical review responsibility for research assigned to the Committee.

c. To determine basic principles and design criteria.

d. To provide, at the request of field offices, advice on design and operational problems.

This report, prepared by the Committee on Channel Stabilization and its consultants, for the U. S. Army Engineer District, Walla Walla, presents the requested opinions of the Committee concerning flood control and channel stabilization improvements on the Snake River in the Jackson Hole, Wyoming, area.

Copies of this and other reports of the Committee on Channel Stabilization can be obtained from the U. S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, Mississippi 39180.

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JACKSON HOLE FLOOD CONTROL PROJECT

Introduction

1. At the 28th meeting of the Committee on Channel Stabilization, held in Vicksburg, Mississippi, on 22-23 May 1973, a representative of the U. S. Army Engineer District, Walla Walla, described the Jackson Hole Flood Control Project on the Snake River in Wyoming and requested the advice of the Committee on certain aspects of the project. At its 29th meeting, held in Jackson, Wyoming, on 18-19 September 1973, the Committee inspected and further discussed various aspects of the project. Specific questions that were submitted in writing by the District representative at the May meeting are repeated hereinafter, followed in each case by the respective response of the Committee as initially prepared after the May meeting and modified after the September inspection and meeting. To clearly identify the project to which this report applies, the authorized project description extracted from the reports supplied by the District is summarized very briefly below. Committee recommendations are presented at the end of the report.

Description of Project

2. Description of Area. The Jackson Hole area is a valley about 10 miles wide and 35 miles long situated at approximately el 6200 on the Snake River in Wyoming immediately south of the headwaters of the stream which originates in Yellowstone Park. The Snake River is the principal tributary of the Columbia River and enters the latter stream some 950 river miles downstream. The existing flood control project extends into the Grand Teton National Park at the project's north extremity. The remainder of the project protects mostly private land with some riparian lands lying between the levees and the private land. The city of Jackson is situated outside the Snake River floodplain about 5 miles to the east of the river.

3. Climatology. The Snake River drainage area above the project has short cool summers, cold winters, an abundance of sunshine, generally low humidities, and a moderate amount of precipitation. Average annual temperatures are about 38 degrees in the lower valleys and generally range 2 to 3 degrees lower per 1000-ft increase in elevation. At Jackson, Wyoming, typical of lower elevation, recorded temperature extremes have been 101 F and -48 F. Normal annual precipitation in the drainage area ranges from about 15 in. in the lower valleys to more than 50 in. in the mountains. The average for the area is 34.8 in. About 70 percent of the annual precipitation falls as snow during the months of October through May.

4. Channel Characteristics. The Snake River, within the project limits, is characteristically a braided stream with many tree-covered islands, poorly defined and constantly changing flow channels, and many gravel bars. The composition of the materials forming the banks and bottom of the river indicates that the materials are mainly derived from the terrace deposits along both the Snake and Gros Ventre Rivers. Streambed gravels above the mouth of the Gros Ventre River are well-graded and range to a maximum size of 6 to 10 in. Below the mouth of the Gros Ventre River, the sizes of the streambed gravels reflect the character of the Gros Ventre drainage area, are graded to about 2 in. with some cobbles up to 6 in., and are somewhat gapgraded between the No. 4 and No. 30 sieves. Since the main Snake River emerges from Jackson Lake at the upper end of the valley, it does not, in itself, furnish a large quantity of bed-load material. In the lower portions of the valley, however, it carries considerable material derived from bed and bank erosion and materials brought in by tributary streams. Much of the streambed material in the project reach is the result of the disastrous Gros Ventre River flood of 1927 when a natural landslide dam 14 miles upstream of the confluence gave way, washing all manner of streambed and bank materials into the Snake River. Surveys since 1954 of 51 channel cross sections within project limits indicate an average increase in channel cross-sectional area (below the 33,000-cfs flow line) of 868 sq ft below the mouth of the Gros Ventre River, and only

38 sq ft above that point. Since the Gros Ventre River contributes less than 20 percent of the annual Snake River flow at the Jackson-Wilson Bridge, the increased degradation results from the change in normal river regime due to a sudden influx of bed-load material greater than can be efficiently carried by the river.

5. Past Floods. Snake River floods in the project area result primarily from snowmelt and occur in a rather regular pattern of prolonged high flows in May, June, and July. At the project, peaks over 20,000 cfs have occurred in 11 years of the 65-year period 1904 through 1968; and peak discharges greater than nominal bank-full capacity, about 10,000 cfs, have occurred in 56 of the 65 years. The largest known flood, which occurred in 1894 in upper Snake River, had an estimated peak discharge at the project of 41,000 cfs, while that of 1918 was estimated at 32,500 cfs.

6. Flood Characteristics. In the project area, prior to the present system of bank protection, the Snake River flowed through a maze of braided channels with relatively shallow depths and with banks 1000 to 4000 ft apart. Since the stream gradient is about 19 ft per mile, flood stages resulted in a raging torrent. Damages began at about 5000 cfs, and appreciable damages resulted from discharges of 8000 cfs. Extensive bed-load movement and channel changes occurred annually during the spring flood; and prior to the construction of flood control works, extensive channel changes endangered vast acreages of range land. Operation of upstream storage at Jackson Lake provided some benefit by reducing peak flood period discharges in the project reach, but increased the exposure to bank erosion and possible avulsion from sustained moderately high reservoir releases during summer months. Since these relatively high sustained summer flows seriously aggravated bank erosion and were a continual hazard to local interests, bank protection was considered a necessity.

7. Standard Project Flood. The standard project flood is based on the assumption of the most critical snowmelt temperature sequence and ground conditions for production of runoff that have occurred in the past, as indicated by available records. This, plus study of past

floods, resulted in an estimated standard project flood for Snake River at the project site with a peak discharge of 45,000 cfs and a 90-day volume of about 2.6 million acre-feet, or 26-in. average depth for the drainage area. This is the design discharge for the existing project.

8. Project Design Features. Original design of the Jackson Hole levee system provided for approximately 23 miles of revetted levee with gradual sweeping curves to minimize direct attack by the river current. To prevent undermining, the riprap toe was set 3 ft below thalweg control, a line connecting lowest points of the stream as determined from preconstruction surveys. The upper limit of riprap protection was established on the basis of performance of previously constructed gravel levees. Past experience had indicated that with 1-on-4 slopes no erosion occurred where water depths were less than 4 ft and flows were laminar in nature paralleling the levee alignment. The top of riprap was established at the three-year frequency flood elevation (15,000 cfs below the Gros Ventre River, 12,500 cfs above), which would allow about 3 ft of water over the top of riprap at most places and up to 4 ft at isolated locations at design flood levels (45,000 cfs). The normal riprap thickness is 18 in., except that the thickness is increased to 24 in. for the bottom 5 ft or where placement is below the flowing water surface. Above the top of riprap, the 1-on-4 gravel slope is protected by an 18-in.-thick zone of coarse cobbles raked from the interior of the levee. Riprap sizes range from 20 to 400 lb with 75 percent of the pieces weighing at least 100 lb and stone up to 1000 lb in the toe. The top of the levee provides 3 ft of freeboard above design flow level. Distance between levees is about 1000 ft.

9. Existing Channel Conditions. The existing levee system has generally confined the stream within a horizontal distance of approximately 1000 ft, but this reduction in width has not essentially reduced its strong braiding tendency and may have increased this tendency. Considerable bed-load movement and shifting of gravel bars are constantly occurring. The higher, tree-covered islands have remained relatively intact, but the positions of low-flow channels are constantly changing. Generally, the low flows concentrate in one to three main

channels. Portions of these channels often become plugged, creating increased velocities through the remaining channel routes, and often new channels are formed. As a result, relatively short reaches of the levee are subject to direct impingement, increased velocity flow, and severe attack. These impingement areas often shift annually. Although extremely high flows have not occurred since the levee project was completed, direct impingement of moderate flows has caused damage to the levee erosion protection at several locations.

Questions and Responses

10. Question No. 1. Can deposition or erosion of bed-load material be predicted?

Response. The Snake River in the Jackson Hole area is a highly unstable braided stream flowing in a bed of noncohesive material, and its discharge varies with the amount of precipitation over the basin and with the rate of melting of the snowpack. It follows, therefore, that this system involves so many unpredictable variables as to preclude accurate short-term prediction of areas and amounts of deposition or erosion. However, periodic field measurements of streambed cross sections at the established ranges over the full length of the floodway should provide a useful degree of guidance for engineering studies and judgment in the development of long-term plans for remedial measures.

11. Question No. 2. Will channel eventually stabilize--when and to what configuration?

Response. The channel is not likely to stabilize naturally because there will always be movement of bed material into the project reach of the Snake River from tributary streams and movement within the channel will depend on widely varying discharge patterns over the years. Complete stability could only be attained by controlling sediment input and lining the channel or constructing an inordinate number of control structures; and such measures would probably not be acceptable due to high costs and environmental constraints. An improved degree of channel stability could be attained by reconstructing the levees to provide channel widths and curvatures that would be more conducive to channel stability; but the high cost, the abandonment of parts of the present project levees, and the taking of more lands probably would be unacceptable. Some insight might be gained regarding channel stabilization characteristics from a study of natural conditions in the channel reach from the upstream end of the project to Jackson Lake by a consultant who is an expert on alluvial rivers.

12. Question No. 3. The tractive force method for riprap design does not work due to local stresses caused by angle of flow attack and by increased velocities caused by isolation of flow plus increased gradient resulting from island or bar buildup. This bar buildup gives localized increased velocities and depths that cannot be computed by normal backwater computations. How do you make computations for these conditions?

Response. Critical tractive force analysis can be used for most portions of the stream, except where direct impingement occurs, through analysis of field velocity measurements along banklines where extreme gradients develop. The most critical conditions expected at design flow may be estimated from measurements made at several lesser flows and extrapolated to the design condition. In areas where direct impingement is anticipated, revetment toes could be lowered. However, as locations of the most critical points of attack are in most cases unpredictable and may occur anywhere in the reach during the life of the project, full protection for this maximum condition prior to its development may not be economically feasible. It may be advisable to design most of the riprap protection for average conditions and depend on flood-fight maintenance of the levees in localized areas during a major flood event. The use of corrective dredging to keep the channel in a central location during low-flow periods by excavating a low-water channel across central bars and blocking some of the critical levee-side channels would reduce nonselective overprotection of the levees; but this work would need to be repeated periodically due to channel migration and this alternative probably would not be environmentally acceptable.

13. Question No. 4. Vegetation buildup is unpredictable on islands and bars. Coefficient of roughness is unpredictable. Suggestions are solicited.

Response. Backwater analysis is normally coordinated with field measurements of stage-discharge relationships, and the roughness coefficients are extrapolated to design flow conditions. Where flow over vegetated islands and bars has not occurred during the observed field flow conditions, a conservatively high value of roughness (say, Manning's $n = 0.12$) should be used. Vegetation is disappearing from areas between levees and could be completely gone in a few years which will simplify the selection of roughness coefficients. Since bar and island positions are not stable, levee grades should be established to anticipate variations in bar and island locations. It is suggested that the design water-surface profile be based on straight lines of constant slopes connecting the peaks of the computed profile. As the channel will continue to reshape its bed and bars will migrate downstream, consideration should be given to the possibility of new peaks developing between and higher than the computed peaks.

14. Question No. 5. Could sampling program of depths, velocities and bed-load movement, etc., be set up to develop a prototype model on which to base design of levee height, toe depth, and required riprap? Would this be a better approach than a conventional design based on theoretical computations?

Response. A program of field measurements of water-surface slopes, channel cross sections, and velocities in a selected typical high-velocity reach, as proposed by the Walla Walla District, is required to verify or modify the design water-surface profile based on conventional theoretical computations. Actual measurements on any stream are needed because theoretical computations cannot possibly consider all parameters; and even though some parameters cannot be measured, the results of field measurements will include the influence of unmeasured parameters. Levee grades and heights of revetment should be based on the revised design water-surface profile. Revetment size should be based on bank velocities corresponding to the design water surface with consideration being given to the fact that direct impingement of moderate flows (15,000 cfs) may cause local damage more severe than the design flow. Attempts to measure bed-load movement would be of no practical value because of the great disparity in such movement between low-flow and design-flood conditions.

15. Question No. 6. Raked cobble was used on the upper portion of some levee sections on the Jackson Hole project. Views are solicited on the adequacy of this design at present time.

Response. The rake cobble used on the upper portion of the levee section provides some limited protection when laid on slopes that are flat enough. However, the effectiveness of this rounded-cobble revetment is so dependent upon gravitational forces that total failure of the revetment will result when tractive forces are sufficient to remove the underlying fine material. This weakness of raked cobble might possibly be counteracted by some type of gridwork (either precast concrete bottomless boxes or gabion-type boxes) to hold the cobbles in place. However, it is believed that graded angular riprap revetment adequate to meet the anticipated tractive force in the upper portion of the levee would be the preferred method of protection from the dual standpoint of cost and effectiveness.

16. Question No. 7. Lowering of thalweg profile in area below Gros Ventre River exposes riprap toe profile to undermining when scour point reaches sides of channel. Will short groins of overtop design tend to channelize flow concentrations to center of channel? What is suggested design and spacing on this type of construction?

Response. Groins of overtop design would tend to channelize flow, but prediction of the effectiveness of this concept will require considerable study. It is difficult to determine proper lengths, heights, and spacings of such structures in a floodway of this type. Also in question is whether the high-velocity turbulent flow over and around the groins would produce severe scouring downstream of the structures and against the levees. Inspection of the two gabion test groins indicates that this type of groin would need to be founded as deep or deeper than the revetment toes in order to prevent undermining and failure of the groins. As this would materially increase their cost, especially when placed in water, it does not appear that the use of gabion groins would be an economical alternative to upgrading the riprap bank revetment. Short rock groins, as were used to close off a levee failure at the downstream end of the project, are useful for this purpose but probably also would be more costly than upgrading the revetted levees for the total project.

17. Question No. 8. Would use of riprap to economical depth of burial plus an apron (continuous or intermittent) of gabion mattress be a practical means of extending bank protection below maximum scour depth? Would this solution be better for structures (bridge approaches) since it would probably not be economically feasible for total project? Has the Committee had any experience with this method? Design? Construction costs?

Response. The Committee has had no specific experience with use of riprap to economical depth of burial plus a gabion-mattress apron to below the maximum scour depth. The Los Angeles and Sacramento Districts have installed gabions with toe mattress for bank protection, but it is not known whether a gabion mattress has ever been installed as toe protection for riprap revetment. Based on the limited amount of damage which has occurred to the riprap revetment since the project has been completed and the increased cost of placing a gabion mattress, particularly in water, it is concluded that the use of this means of extending bank protection below maximum scour depth would not be practical.

18. Question No. 9. Would a system of permeable groins similar to "Kellner Jetty Type" be workable on such a stream as Snake River where velocities are high and bed-load materials are coarse?

Response. A system of either "Kellner Jetty" type structures or pile dikes would probably be effective if they could be constructed strong enough to withstand the forces of drift impingement and debris loading. Such structures would soon become semi-impermeable due to rapid debris buildup and should then perform about like rock or gabion structures. However, it is doubted that it would be practicable or economical to build this type of structure strong enough to withstand the forces that would be produced by the large load of heavy drift carried by this floodway. Also, such structures do not provide positive control of low flows which allows meandering to continue within the braided channel, undercutting banks between the structures, except when spaced closely which makes their cost excessive. Such permeable structures frequently fail when drift piles and sand or gravel deposits cause locally intense flow concentrations to undermine the structure.

19. Questions Nos. 10-13 (restated). (a) Is there a solution for the existing levee project that could be economically justified and would be aesthetically acceptable? (b) What plan of protection, and what alternative plans, would the Committee propose for study?

Response to (a). It is understood that complete reformulation of the project is required for the design deficiency report currently under preparation. Presumably, this will include consideration of all alternatives such as upstream storage; floodplain zoning; concrete-lined channel; stabilizer or groin-controlled channel; realignment of the levees so the channel will be compatible with its natural meandering tendency, thereby eliminating direct impingement on the levees and reducing maintenance costs; major rehabilitation of the levee system; periodic rehabilitation of the levee system; and continuation of present maintenance (including emergency flood-fighting activities). Although establishment of economic justification of projects is not within the scope of the Committee's functions, it appears that all but the last three alternative plans are clearly not practical or economically justified and, therefore, need not be studied in detail. The Committee concludes that improvement of the project can be successfully developed by detailed consideration of the last three alternatives. The adopted plan probably would be as aesthetically acceptable as the present project. Development of the improved plan of protection should involve the following hydraulic studies:

(1) Review basin hydrology to verify or revise design flood discharge.

(2) Utilizing theoretical backwater analysis based on measured field data, establish a new design flood profile as discussed

under responses to Questions Nos. 4 and 5. Reestablish levee and revetment heights accordingly.

(3) Obtain velocity and scour depth measurements at critical points in the selected study reach through rising and falling stages of a flow hydrograph to verify the riprap design as discussed under the responses to Question No. 3.

Response to (b). As referred to in response to Questions Nos. 10-13 (a), the Committee recommends that the following three alternative plans be studied in detail:

(1) Plan 1. Major Rehabilitation of Levee System. This plan would provide for rehabilitation of the levee system to reduce maintenance costs to a nominal level and restore essentially complete flood protection to the project area. Under this plan, the riprap protection should be raised to 1 ft above the new design water-surface profile, the levees should be raised where required to provide the desired freeboard for the new design water surface, and the riprap toe should be lowered to 5 ft below the thalweg only in those reaches that are likely to be subjected to direct attack within the economic life of the project. Except in limited existing damaged areas, there appears to be no need to overlay all existing riprap with larger stone as the existing riprap has provided good protection where riprap toes have not failed. However, if the proposed hydraulic studies indicate that the existing riprap is materially deficient in size, then riprap overlay should be provided in those reaches which are likely to be subjected to direct attack within the economic life of the project. While the prediction of reaches that would not be subjected to direct attack is difficult, a study of channel and levee alignments, extent of high ground fronting the levees, tree growth, and streambed materials should result in identification of levee reaches which are not likely to be subjected to direct attack.

(2) Plan 2. Periodic Rehabilitation of Levee System. This plan would provide for rehabilitation of the levee system to reduce maintenance costs by periodically upgrading the existing levees at locations of weakness of a long-term as-need construction basis. This

plan, with possibly some emergency flood-fighting activities, would restore marginally complete flood protection to the project area. Under this plan, the levees and top of riprap protection should be raised, in accordance with the criteria used in the initial project design, in those reaches where the new design water-surface profile is higher than that for which the project was constructed; except in existing reaches of weakness where direct attack occurs on or major flow is along the levees, the riprap protection and levees should be raised as described for Plan 1. The riprap toe should be deepened and overlay of riprap should be provided only at existing damaged areas. In view of the generally favorable performance of the riprap protection since levee construction, deepening of the riprap toe and upgrading of the slope protection in nondamaged areas should not be required under this plan. Therefore, some emergency flood-fighting activities may be required during each flood until periodic long-term rehabilitation under this plan has eliminated all areas of weakness, if this will be possible.

(3) Plan 3. Continue Maintenance as in the Past. Continuation of present operation and maintenance practices on the levee system as in the past without levee rehabilitation as described under Plan 1 or 2 would require repair of all damaged areas as they occur by providing deeper toe protection and an overlay of riprap in and for a short distance upstream and downstream of damaged areas. Under this plan, annual maintenance costs would be high, and extensive emergency flood-fighting activities probably would be required during moderate to major floods. The risk of levee failures before emergency repairs could be made would be high, unless adequate facilities and materials were always readily available for emergency flood fighting.

Recommendations

20. Although the Committee recognizes that existing authorities do not specifically provide for periodic rehabilitation of the levee system on a long-term basis as required for Plan 2, it is recommended that such authority be obtained and that this plan be adopted because it

is the least-cost plan that would provide the desired flood protection with an acceptable low risk of failure of the levee system. Plan 1 would be high in cost and may not be economically justified, but it should be considered in detail to indicate what would be required for a so-called engineering solution of levee rehabilitation that would provide essentially complete flood protection with annual maintenance costs probably within the payment capability of local interests. Plan 3 should be considered in detail to emphasize the false sense of security given by the present levee system, the complete dependence on continued high maintenance and emergency flood-fighting costs, and the high risk of levee failures during major floods. As a part of Plan 2, it is recommended that long-range studies, utilizing periodic aerial photographs and channel sections at the sediment ranges, be made in an attempt to predict future channel meander characteristics and locations of deficient levee reaches. There is evidence that the stream is aggrading between levees, and it is possible that the aggradation tendency will increase during the next several years. Therefore, long-range studies should include a review of all hydrographic, metamorphic, and hydrologic data; geologic events and history; and man's historic activities on the river and adjacent lands, including control of river flows. A plan should be established for the continued data collection for those factors that will influence the river's behavior. Appropriate meetings of all those interested in the river and the adjacent area should be held so that a common long-range goal can be obtained that will be best for those involved and for control of the river.