Experimental study on the flood control impact of the new built Yellow River Bridge in Lanzhou-Chongqing Railway

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Abstract. The proposed Yangjiawan super-large bridge is located in Lanzhou section of the Yellow River,constructed for Lanzhou-Chongqing railway crossing the Yellow River.This paper adopts mobile bed experiments to simulate the channel near the bridge site,mainly studies flow direction,velocity distribution,surface slope,backwater and the rule of the topographic change near the bridge site before and after the completion of the bridge in the water discharge of $Q_{average}$,$Q_{5\%}$ and $Q_{1\%}$.The flood control impact after the completion of the bridge was discussed and the preventive measures were put forward.

Introduction

The lanzhou-chongqing railway is an important channel connecting northwest and southwest and other regions.The northern end of the line is linked together with Longhai, Lanxin,Lanqing,Baolan and the planning construction of Longhai passenger transport line through the Lanzhou hub; the middle part is linked together with Baocheng and Dacheng railway, after access Chongqing hub,it is linked to Chengyu,Chuanqian,Xiangyu,Yuhuai and the planning construction of Huhanrong Passenger Dedicated Line.Lanyu railway is an interregional network railway in the western region[1].

The proposed Yangjiawan super-large bridge is built for the north ring freight line of Lanzhou hub,which linked Sangyuanzi and Qingbaishi station,to cross the Yellow River.The proposed Yangjiawan super-large bridge is located in the mainstream of the Yellow River in Yangjiawan village,Qingbaishi township,Chengguan district of Lanzhou,103.36 degrees east longitude and 36.09 degrees north latitude.The bridge site is located at 13.0 km away from the upstream Lanzhou hydrologic station with the drainage area of 223051 km^2.The suface slope in flood period is 0.31‰,and the river bed is made up of pebble,and pebble and silty loam.

Lanzhou section of the Yellow River begins at Xiliugou and finishes at Sangyuanxia railway station,with a total length of 44.84km,according to floods of 100 years frequency of the design flood level,the total head is 32.42m,with an average surface slope of 0.723‰;according to average elevation of the river bottom to calculate,the river bottom head is 43.72m,with an average surface slope of 0.975‰,it can be seen that the stream fall at the time of flood is 11.3m smaller than river head and the water surface slope is 0.252‰ smaller than river slope.

Hydrologic sediment character and channel change

Lanzhou hydrologic station was constructed in 1934, accumulated over a long series of data by observations,and it can be used as the representative station of Lanzhou section of Yellow River.Due to the influence of supply conditions,the annual runoff distribution of Lanzhou station has four distinct seasons,the general rules are that the precipitation is little in winter(from December to the next February),runoff relies on the supply of groundwater,the minimum flow appears from January to February,and runoff is in dry seasons during this period[2]. The inflow in natural state accounts for 11.2% of the annual total and at present conditions accounts for 16%;the temperature rises obviously after spring(from March to May),the snow of drainage basin melts and the storage-ice of river network thaws,and the flow has a significant increase. The inflow in natural state accounts for 16.8% of the annual total and at present conditions accounts for 23.3%;the basin precipitation is plentiful and concentrative from June to August when the river floods,the inflow in natural state accounts for 38.1% of the annual total and at present conditions accounts for 33.0%;From September to November,the inflow in natural state accounts for 37.0% of the annual total and at present conditions accounts for 27.8%.The percentages of the mean discharge of every month that accounts for the annual amount at different times in Lanzhou hydrologic station are mentioned in table 1.According to the weighted average of nine drill bores data of main channel of Yangjiawan super-large bridge,it can be obtained that the mean sediment grain size of river bed is 46.1mm,and the characteristic grade sizes are listed in table 2.

Table 1.The statistical table of the mean discharge of every month accounting for the annual amount at different times in Lanzhou hydrologic station

average flow within the prescribed time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	year
1956-1985 year (m^3/s)	464	431	453	657	1030	1210	1850	1780	1930	1550	839	528	1060
every month accounting for the annual amount(%)	3.7	3.4	3.6	5.2	8.1	9.5	14.5	14.0	15.2	12.2	6.6	4.2	100
1986-2005 year (m^3/s)	519	477	477	732	1110	1070	1110	1100	987	954	825	592	829
every month accounting for the annual amount(%)	5.2	4.8	4.8	7.4	11.2	10.8	11.2	11.1	9.9	9.6	8.3	6.0	100

Table 2. The sediment gradation of prototype riverbed

characteristic grade sizes	d_{95} (mm)	d_{75} (mm)	d_{50} (mm)	d_{25} (mm)	d_{cp} (mm)	$K_f = \sqrt{d_{75}/d_{25}}$	γ_s (kg/m^3)
prototype	170	65	26.5	5.4	46.3	3.47	2.74

Lanzhou section of Yellow River crosses urban area of Lanzhou and the geological structure conditions is better.By researching and consulting the literature of historical extraordinary flood events ,it can be obtained that there were no obvious diversions and changes occurred in the upstream and downstream river near Zhongshan Bridge in the condition of extraordinary floods in history[3].The hydrologic sectional drawings of Lanzhou hydrologic station are shown in figure 1,it can be seen from that the scour equilibrium of river channel is in the balance state.Geological conditions of Lanzhou section of Yellow River are better,with a smooth channel,small gradients and relatively stable flow,and the river bed is made up of pebbles,sand pebble and sand loam[4].If there are no big floods,river longitudinal changes are in a relatively stable state.Slowly silting will be the mainly characteristic of the river longitudinal changes of Lanzhou section of the Yellow River in the future.

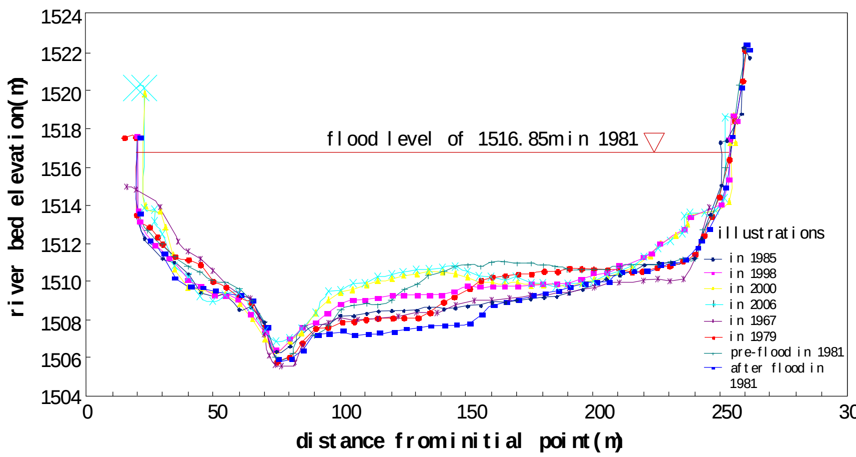

Figure 1.The hydrologic sectional drawings of Lanzhou hydrologic station

Model design and verification

Model design. According to the dimensions of the design paper, the model was manufactured in scale.Guarantee the flow similarity near bridge crossing on the basis of the elevation and the location setting of bridge floor and pier.[5]Due to the imperfect sediment theory,sediment runoff scale and scouring time are not accurate,the only method is bed deformation verification[6,7].Consulting the previous research results and the verification test,when l_{qs}=130 , l_{t2}=480,the model have a nice similarity with prototype.It is proved that flow model in movement similarity is satisfied in many respects such as movement similarity,and adopting this model to forecast is reliable[8].

boundary definition. The channel segment experimental study takes the channel segment with smooth flow in 3800m the upriver from the proposed Yangjiawan super-large bridge as the inlet boundary of model test,and the inlet is located at about 1000m from Donggang Yellow River;and takes the channel segment with smooth flow in 1000m the downstream from Yangjiawan super-large bridge as the outlet boundary.The elevations of inlet and outlet on both sides were taken above the floods of 100 years frequency,the same as the both sides of the river bed.The length of the test section from inlet to outlet is about 4800m,and it spans 1400m at the widest point.The section includes three hydrographic large sections.The bridge site of Yangjiawan bridge is located in the terminal of backwwater of Xiaoxia hydropower station whose water flows gently.The normal angel bridge is about 25°and the main channel of mainstream’s width is probably 250m.Bridge is located in the reverse curve whose curve radius R=800m.The bridge’s level is railway□of country,by the same time,it’s center range is HDK27+556,total length is 1437m with China railway standard and 0.2g peak acceleration of brake earthquake.The beam crossing the main river channel uses a league(40+2×64+40) m continuous style,and the bridge crossing river is about 912m long.The once-in-a-century design flow rate is 6500m^3/s,the design level containing free height is 1515.84m and the girder fulcrum height of the main river channel is 1522.22m(4#pier).The infrastructure is constructed by T abutment,round side pier with a 10.0m length,5.6m width with a steel bar built surface.Basic forms:bored piles whose diameter is 1.50m is used for the foundation of the continuous beam bridge pier and the remaining is the same stye with a 1.25m diameter.

The river bed scour and silting deformation verification. According to the bed load transport data of Lanzhou hydrologic station,it shows that when Q=2040m^3/s,the sediment transport rate of the whole section G_b=17.1kg/s, the bed load mean grain diameter d_{cp}=32.66mm,the corresponding surface width B=225m,the mean depth h=4.5m,the flow velocity V=2.32m/s.Calculate bed load transport rate according to the following formula:

$$G_b = Bfg_s d(V - V_c)\left(\frac{V}{V_c}\right)^3\left(\frac{d}{h}\right)^{1/4} \quad (1)$$

Among them,the initial velocity is calculated by Sharmove formula:

$$V_C = 4.6d^{1/3}h^{1/6} \quad (2)$$

The coefficient f can be derived and f=0.00381.Then substitute the flow condition of verifying flow and obtain the sand volume G_b of verifying river bed deformation.Such as the flow condition of Q=3000m^3/s , h=4.0m , J=0.001 , B=300m , V=2.64m/s,the bed load mean grain diameter can be calculated by formula (1).

According to the measured data,when Q=3000m^3/s,the sediment transport rate G_{gb}=27.5kg/s,and others flow rate stages of sediment transport rate can be obtained by measured data and theoretical calculation.

Bridge crossing scour calculation

General scouring calculation. General scouring refers to the scour of necked-down section and scouring depth refers to a vertical water depth from design flood level after finishing the scouring of river bed[9].The upstream water of bridge opening sharply focused flow into bridge opening,and the necked-down section is formed near the downstream of bridge opening where the effective flow cross-section is minimum,with the maximum velocity and deepest scouring[10].The flow velocity and direction change sharply,the velocity gradient and the sheer stress of the surface bed are big,sediment movement is intense and the scouring of surface bed is obvious.In the downstream of the necked-down section,the flow gradually spreads and returns to natural state in the distance.

When the incoming sediment amount from upstream channel section under the bridge is less than the sediment carrying capacity(mainly the bed load),there had scoured.With the development of the scour,the cross section under the bridge enlarges,the velocity and the sediment carrying capacity gradually decrease.The incoming sediment amount from upstream and sand discharge capacity tend to be balanced,scouring tends to stop and the scour depth reaches the maximum[11].On the basis of the preferred formula"64-2 formula",which calculates the sandiness river bed in Highway and Bridge of Survey and Design Standard(JTJ 062),Gao Dongguang had calculated the general scouring in the condition of 6500m^3/s of the hundred year flow.

$$h_p = 1.04\left(A\frac{Q_2}{Q_C} \right)^{0.9} \left(\frac{B_c}{(1-l)mB_2} \right)^{0.66} h_{mc} \tag{3}$$

Where h_p is the maximum depth of under bridge channel after general scouring(m);Q_2 is design flow rate through the under bridge channel(m^3/s);Q_2=5260 m^3/s;Q_c is the natural channel flow of the computation cross-section(m^3/s);B_2 is the width of channel(m),B_2 =400;B_c is the partial bridge opening clear width(m),B_c =357;l is the ratio of the pier anti-water area and under bridge flow area in design level,l=0.915;A is concentration factor of unit discharge,A=1.13;m is lateral compression coefficient of pier water,m=0.992;h_{mc} is the maximum depth of under bridge channel of the computation cross-section,h_{mc} =17m.

By computation,the maximum water depth h_p after general scouring is 19.72m,namely the general scour depth is 2.72m;and the general scour depth is 2.28m when the flow rate is 3000m^3/s.

The local scour calculation. It is bridge pier blocking the flow that occurs local scour, the blocked flow around the pier has an effect on bed surface sediment with intense eddy.Therefore,the scour pit is generated around the pier,especially near the upstream face.In the past research achievements of bridge pier local scour formulas,the semi-empirical and semi-theoretical formulas accounted for a large proportion.Based on certain theories and some assumptions,the semi-empirical and semi-theoretical formulas of pier local scour are derived and some parameters are determined by combining with the test data.

China railway cooperates with highway system,on the basis of the theory of sediment incipient motion,according to the measured data of pier local scour and some test data at home and abroad,the established "65-2 modifier formulas" is as follows:

$$h_b = 0.46K_x B_1^{0.6} h^{0.15} d^{-0.068} \left(\frac{v - v_0'}{v - v_0'} \right)^n \tag{4}$$

Among them,

$$v_0 = \left(\frac{h}{d} \right)^{0.14} \left(29d + 0.000000605\frac{10+h}{d^{0.72}} \right)^{0.5} \tag{5}$$

$$v_0' = 0.645\left(\frac{d}{B_1} \right)^{0.053} v_0 \tag{6}$$

Where h_b is pier local scour depth (m);K_ξ is pier shape coefficient;B_1 is pier calculative width (m), B_2 takes on a value 400;H is marching flow depth before pier (m);d is mean sediment grain size in scour layer (m);v is marching velocity before pier (m/s);v_0 is initial velocity of bed material (m/s); $v'0$ is initial scour velocity before pier;n is index,n=1.0 when clean water scouring ($v \le v_0$),and when movable bed scouring,

$$n = \left(\frac{v_0}{v} \right)^{9.35+2.23\lg d} \tag{7}$$

Due to the damming which is generated at large flow,the pier local scour with the bankfull discharge of 3000 m^3/s is calculated.Take values according to the measurement and calculation,where h_b=11m,K_ξ=0.925,B_1=7.46m,d=0.0463m,v=2.81m/s,v_0=2.23 m/s,$v'0$=1.10 m/s, n=0.221.

By calculating,the pier local scour depth is 2.75m when the discharge is 3000 m^3/s.

Conclusions

The bridge pier anti-water area accounts for 13.8% of the total discharge area,the height of swell is 0.18m with a region of influence of 1300m in a hundred-year flood.The general scouring of bridge site cross section channel is from 1 to 2.5m,the maximum local scour depth is 2.75m,the pier foundation embeds in bedrock and the scour depth can not influence the safety of the bridge.

There are 18 bridges which exist respective local damming phenomenon in Lanzhou section of the Yellow River from Xiliugou to Sangyuanxia.Yangjiawan bridge construction engineering has no obvious impact on the channel stability and navigation,but has certain influence on the flood discharge,so it is need to take remedial measures.

Due to the stream guidance of the pier,the top spot of the mainstream of downstream moved 65m after bridge construction,and sedimentation was happened at right bank,it is suggested that the river levee of left bank and the structures should be strengthened.Because of the backwater height of 18cm after the construction of the bridge,it is recommended that some related measures should be taken to eliminate the negative impact of the flood control when the embankment of the riverside road near the engineering was constructed by municipal government.

References

[1] Cang Junjie,Gao Xuejun,Zhao Changrui.The test report of channel change of scour and silting in Lanzhou Section of the Yellow River[R].Lanzhou:flood-control headquarters in Gansu Province,1994.

[2]Li Baoru.Physical model design for river sedimentation in China[J].Journal of Hydrodynamics,Ser.A,Vol.6,SUP,1991.

[3]The industrial standard of the People's Republic of China"Testing Regulations of River Model"(SL 99-95),published on June 26,1999 by Ministry of Water Resources of the People's Republic of China,and put into effect on December 1,1999.

[4]Yu Bangyi.The study and application of the similarity theory of river model and automatic observation and control technology[D].Nanjing:Hohai university,2003.

[5]Zhang Hongwu.Advances in movable-bed model similarity laws of river[J].Advances in Water

Science,2001,12(2),256-263.
[6]Hui Yujia.River model test[M].China water&power press,1999.
[7]Sun Dongpo,Wang Jun,Yu Hui. The river model experiment study of two spans grand bridge in Weinan[J].China Water Transport,2007,5(1),95-97.
[8]Liu Youlu.The cut-through model experiment report in Lanzhou section of Yellow River[R],Lanzhou Railway University,1994.
[9]Qian Ning.The distorted river model rate of shifting bed[M].Science Press,1957.
[10]Ji Richen,He Wenshe,Fang Zhenye.Experimental and theoretical study of skew bridge backwater[J].Advances in Water Science,2007.18(4),504-508.
[11]Tang Fangfang,Guo Chunqing,Chang Quanjun.Great bridge of Wei River impact analysis on both banks' embankment[J].China Rural Water and Hydropower, 2010,(5),117-120.