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FAILURE OF SUKKUR BARRAGE GATE NO. 31 AND REPLACEMENT PROGRAMMES STUDY

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ABSTRACT

The Sukkur Barrage was commissioned in 1932 and is the first barrage which was constructed on Main Indus. It has got 66 gates of 60 ft. span each. It has got 5 pocket gates on the right bank and 7 gates on the left pocket. It has got 3 canals offtaking from right side and 4 canals on the left bank.

It was on the 19-20th night of December 1982 that gate No. 31 went with a big bang, shearing skin plate and back bow girders. Water started shooting out since the barrage was working under full head conditions.

Immediately, emptying of pond was started to contain the standing wave to limit the damage to the apron and pavement. After pond was practically emptied, it was decided to replace the gate by removing one gate from one of the closed spans. Due to paucity of pontoons and tug boats and small cranes, to work in flowing water, Karachi shipyard, Army and Navy were called in to assist in supplying the skilled labour and the equipment. The gate was replaced within a fortnight during the closure period which was slightly advanced. Thus a big disaster was averted.

O.D.A. (Overseas Development Association) U.K. offered to replace all the gates through an out right grant to Government of Sindh. Sir M.M.P. were thereafter appointed as Consultants. They engaged M/s Newton Chamber Engineering Ltd. who were successors of "Ransoms & Rapiers", the original manufacturers of the barrage gates. M/s. Newton Chambers designed a caisson gate which works in low flow period upto pond level of 195.5. Todate they have replaced 27 gates and the balance gates are proposed to be replaced by 15th April 1991.

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HISTORY OF PROJECT :

1. The word "Sindh" means the country of Indus River. In this tract, the mighty Indus River forms the backbone of Agricultural economy and the prosperity of the population which directly or indirectly depends upon the waters of this river. The population of Sindh is about 19 millions (1981 census). Its total ara is 46,944 Sq. miles out of which roughly half is mountainous and sandy hills, the other half being suitable for Agriculture. The total canal irrigated area for Kharif and Rabi (1981-82) is 4,530,300 and 3,355,371 acres respectively, out of total commanded area of 13.2 million acres. The summer is long drawn out and shade temperatures cross 120^{0}F. Rainfall is scanty and unreliable and most of it falls in July and August, the average being 3".

2. The area was served by series of highly developed innundation canals from the Indus from times immemorial. The project for constructing a canal from Rohri to Hyderabad with weir control on Indus was twice abandoned in 1872 and 1892, as unproductive. It was however, realised that continuous increase of irrigation in upper reaches, would, as a consequence, force the construction of weir in Sindh. The disastrously low innundation of 1918 which created severe famine conditions in Sindh, provided the most striking proof of the necessity for a barrage and assured irrigation supplies.

MAIN FEATURES OF BARRAGE :

3. (a) Sukkur Barrage is located on the River Indus with coordinates of 68^{0} - 53' E and 27^{0} - 41' N. It is about 3 miles down stream of the "Ayub Bridge" across the Bukkur gorge.

(b) It was the first barrage constructed across mighty Indus. After the completion of Indus Basin replacement work, it becomes, the fifth in sequence, out of the total six on the river.

(c) The barrage has a weir founded on alluvium, properly boxed on the upstream and downstream.

(d) The barrage comprises 66 spans of 60' each and is divided into 3 sections by 2 divide walls. The right and left scouring sluices have 5 and 7 spans respectively. The remaining 54 river gates 6 to 59 are originally divided into 6 groups each of 9 gates with larger piers between the groups and a large central pier located between pier 32 and 33. Because of sediment problems on the right side, hydraulic model experiments were performed at Poona Research Station to determine appropriate improvements in the approach conditions of the river to eliminate silt problem in R.B. canals. The experiments recommended the construction of an island and closing gates 6 - 14. Gate No. 23 was to be closed to form the base of the outer bank. The main objective of these works was to develop curvature of the flow in the right bank approach channel with the flow in the tail channel controlled by gates 15 - 23. The resulting modifications are shown as exhibit No. 1.

The ordinary piers are 10' thick while the end abutments and the intermediate abutment piers are 25' thick. Weir cill is R.L. 177 while scouring sluices cill is at R.L. 176.

(e) The piers support two separate bridges. On the upstream end they have high level gate bridge, consisting of two R.C.C. concrete archs. The upstream arch is 8' wide and downstream one is 5' wide with a 13' wide clear gap. In this gap hang the gates and the counter weights.

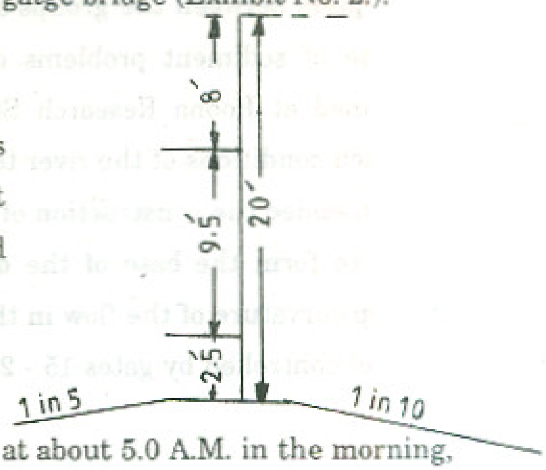
The downstream ends of piers support Road bridge over R.C.C. arch. These R.C.C. archs are 25' wide with their springing at R.L. 201, slightly above estimated high flood. There is a clear roadway of 19' flanked by 3' - 6" footpath on one side; the footpath on the other side was removed due to traffic conjestion. The length of barrage is 4725 ft. between regulator faces.

FAILURE OF GATE NO. 31

4. The barrage gates are stony roller type gates. The scour sluices gates were originally 22' - 6" deep and the river gates 18' - 6" deep but the depth of gates was later increased by 18" to cater for increased pond level requirements. The designed pond level was 194.5 but due to increased water requirements, the maximum pond level has increased to R.L. 198.4. The gate structure generally consists of a vertical steel skin plate 1/2" thick, supported on the downstream side by vertical stiffeners (channels) which in turn are supported on 2 main horizontal bow girders. The end of the main girders are connected to vertical end beams within the grooves which bear against the stony roller frames. The gates are suspended from the operating gear by steel wire ropes situated at each end of the gate which pass over the winding drums to the steel counterweight boxes containing ballast. The two ropes winding drums are connected to a centrally placed gearbox by means of cross shafting which can either be operated manually or by means of

an electrically operated trolly, running on rails along the gatge bridge (Exhibit No. 2.).

The rough sketch alongwith two bow girders is shown at the side. The details of bowgirder are shown at later pages. The load distribution between upper and lower girders is approx. 40 : 60.



5. It was during 19-20th night of December 1982 at about 5.0 A.M. in the morning, that the lower bowgirder of gate No. 31 went with a big bang and the whole gate settled at about 7 ft. above the cill crushing the skin plate as well as upper girder. It being 'December', the gates completely were closed as Kotri Barrage does not get any winter supplies.

The annual closure which was to take place few days latger was advanced and in order to save the pavement, pond level was ordered to be dropped so that the cut off should be reduced to practically Nil. After the gates were fully open, the plan was evolved to replace the gate. It was decided to complete the job within closure period of 15 days. The whole job was to be done while 6-7 ft. water was flowing over the crest. It was therefore decided to requisition the services of Navy to bring some pontoons which should be able to handle the load of about 40 tons, the weight of girder, plus a small crane, if necessary. The Karachi Shipping Corrporation was also contacted to supply the skilled labour including mechanics, welders and foremen etc.

6. The island portion of the barrage had 9 new gates, as these gates were used only for first 3 initial years. It was decided to cut gate No. 31, remove it and replace it with one gate from island portion. This strategy worked very well and thus gate No. 31 was made operational with day and night working, during December chilly weather and within scheduled period of a fortnight.

7. It is said that "any failure of structure is engineering success". It is obvious that detailed inspection of failed structure will lead to some conclusions which will help advance the Engineering knowledge and also pinpoint the snags for such failure during construction as well maintenance period. It will therefore be of interest to go into the reasons for sudden failure.

To start with, it was proposed to entrust the study to M/s. NESPAK and actually their team came for preliminary inspection also. Subsequent to this, O.D.A. (Overseas Development Administration) of U.K. offered outright grant for consultancy as well as replacement of all the gates of barrage and regulators. They commissioned M/s. Sir M. Macdonald & Partners and Newton Chamber (Ltd), who were the original manufacturers of gates, in September 1983 and they carried out preliminary inspection of gates during September 1983 and detailed examination during January 1984 closure. Newton Chamber (Ltd), being original manufacturers, had detailed drawings as well as stress diagrams for various members of the bow girders and as such they had the facility of redesigning the same with higher pond level (198.4 as against 194.5 original pond level).

INSPECTION BY CONSULTANTS (The Study) :

8. The barrage gates consisted of a stiffend skin plate bolted to two bow girders and braced together. They are lifted and lowered by wire ropes attached to a 20" deep special-I beam at each end of the gate which is machined for stony rollers which run on a rocking roller path suspended from a bracket above the down-stream casting, concreted into the masonary pier. The upstream casting limits the gates side movement and incorporates the staunching face. The staunching of the gates is achieved by round section bars freely suspended at each end of the gate.

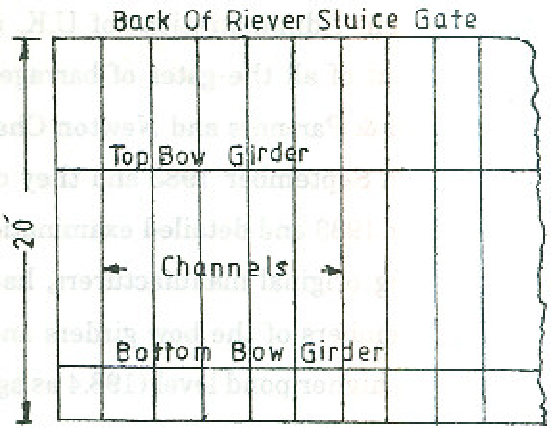
REASONS FOR FAILURE :

9. (a) The main problem has been the corrosion of gates which significantly reduced their strengths. The bow girder structure members and skin plate stiffeners of the gates and back beams suffered the most from corrosion. All the gearing and lifting ropes were still serviceable but there was considerable wear and major overhaul was required.

Skin Plate : Although deeply pitted, these were all in comparatively good condition and are believed to be made from special 1/2" thick Armco steel which is corrosion resistant.

(b) Skin Plate Stiffeners :

A high percentage of these have corroded right through leaving ragged flanges on the bow girder with large holes through the channel section webs. On the river sluices, this damage is mainly at the bottom of the gate where the lower bow girder is attached. On the scouring sluices the damaged area is higher up in the region of the upper bow girder. The fixing bolts were also badly corroded.



STRUCTURAL ANALYSIS OF BOW GIRDER :

10. It will be of interest to calculate original stresses as designed and actual stress (anticipated) at the time of failure of the gate. The calculations for original stresses as designed were done by the department but after the commissioning of Consultants, these stresses were refined. The Consultants also took the actual measurments of the members of gate No. 36 which was practically in the same condition as gate No. 31. This was an assumption which it is considered, gave fairly good idea of the state of affairs at the time of failure of gate No. 31.

While analysing the bow girders, the Consultants have followed the allowable streses by reference to B.S. 449, taking lowest grade of steel, Grade 43. The test on samples from the failed gate shows it to be comparable with this grade. Following the British Standard, the tensile stress was set as 165 N/mm^2 (approx. 10.5 tons sq. inch) as against 8 tons/sq. inch as originally allowed. Compressive stress is a more complex mechanism than the simple yield stress. However analysis has been based on the method outlined in B.S. 449, which is as under :

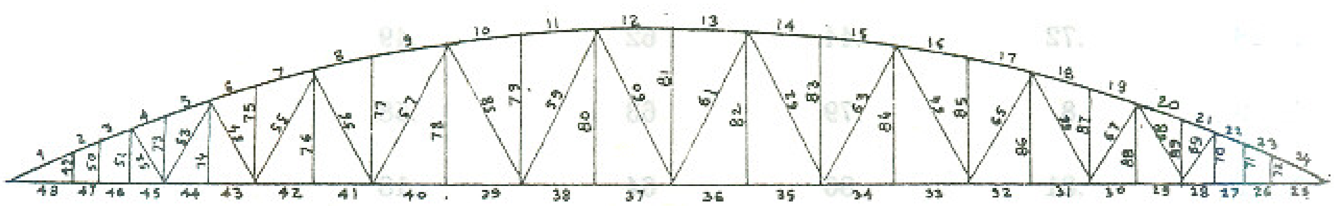
The ratio of actual stress to allowable stress in compression is defined as under :

$$SR = \frac{fc}{Pc} + \frac{fbc}{Pbc}$$

Where	SR	=	Stress ratio,
	fc	=	calculated axial compressive stress
	fbc	=	calculated bending compressive stress
	Pc	=	allowable axial compressive stress
	Pbc	=	allowable bending compressive stress

11. The allowable stress, pbc is dependent upon 2 parameters, the slenderness ratio (L/r), the effective length/radius of gyration) and depth to thickness ratio of the member. The bow girder shown as under consists of series of short members, which means slenderness ratio is generally small, rarely exceeding 90 which makes the threshold effect of D/T as allowable stress in bending. Hence for the purpose of the analysis, pbc has also been taken as 165 N/mm2. Any stress ratio values of less than 1.0 can be considered as safe. Any stress ratio higher than 1.0 is not desirable. However it does not indicate imminent failure as there is substantial factor of safety. This ratio is therefore taken as an indicator to give priority, if it is more than say 1.1.

Typical Bow Girder for river/scour gates.



Member stress ratio for River gate top girdeer (Original design)

No. of Member	Stress Ratio (Orig)	Stress Ratio of gate No. 36	No. of Member	Stress Ratio (Orig)	Stress Ratio of Gate 36
1	.37	.42	43-44	.80	.80
2	.62	.37	45-46	.72	.44
3	.67	.38	47	.56	.42
4-5	.73	.78	48	.47	.46
6-7	.76	1.11	49	.35	.09
8-9	.78	1.12	50	.46	.11
10-11	.77	1.29	51	.64	.28
12.13	1.04	.87	52	.35	.39
14-15	.84	1.25	53	.30	.34

16-17	.78	1.15	54	.60	.76
18-19	.75	1.12	55	.12	.29
20-21	.75	.72	56	.62	.75
22	.67	.39	57	.18	.27
23	.62	.38	58	.58	.78
24	.37	.46	59	.49	.80
25	.47	.46	60	.59	1.10
26	.56	.42	61	.58	.85
27-28	.72	.44	62	.49	.78
29-30	.8	.79	63	.58	1.02
31-32	.81	.86	64	.18	.28
33-34	.87	.91	65	.62	1.02
35-36	.85	.91	66	.12	.13
37-38	.85	.89	67	.60	.81
39-40	.87	.90	68	.30	.28
41-42	.80	.87	69	.61	.39

No. of Member	Stress Ratio (Original)	Stress Ratio gate No. 36
70	.41	.39
71	.35	.15
72	.45	.09

12. It would be observed .that the bow girder comprises of straight portion (2 composite channel) diagonal members (angles) and curved back bow beam comprising of angles and plates. The water load is transferred by the skin plate to two bow girders which in turn transfer the load to piers through roller bearings.

Summary of applied loads (original design)

Upstream water level	=	195.5
River gate cill	=	177.0
H	=	18.5 ft
Load on top girder	=	95.6 Tons
Load on bottom girder	=	191.0 Tons

Roughly the bottom girder carries twice the load as on the top girder.

The examination of stresses indicate that the original design stresses are generally acceptable. The central section of the curved back bow beam is the most heavy stressed member. Highest stress ratio values are for the back curved beam and front channel beams from 0.37 to 1.04 and 0.47 to 0.87 respectively.

13. In order to find out the stresses at the time of failure of gate No. 31, attempt was made by Consultants to establish the picture of stresses by taking the thickness of the members extensively (corroded thickness) and fitting strain meter guage to gate No.36.

The analysis of the results indicated that curved beam member 6-7 showed stress ratio of 1.11 and 12-13 showed 1.29. Even the diagonal members which were stressed to roughly 50% permissible loading (originally) showed as high as 0.85 to 1.02 stress ratios. The result was even confirmed by the strain meter guages. The main cause has ben the corrosion, over the years, of the useful metal. The failure has taken place when the useful metal has corroded by more than 30% in some of the members of upstream curved beam bow girder.

REPLACEMENT PROGRAMME (CASSION GATE)

14. It is generally accepted that a two week closure period in a case of perenial barrage imposes a very serious constraint on the time allowable for access to the gates for inspections, maintenance and eventual replacement. The constraint is caused by the

absence of any facilities to isolate the gate bay The number of alternatives were considered by the Consultants before arriving at final decision. The main difficulties in finding satisfactory solution were as under :

(a) The safety of the barrage floor upstream of the existing gates against uplift.

(b) The absence of grooves or bearers immediately upstream of the gates to which water load could be transferred during replacement of gate.

(c) The presence of the existing upstream gate bridge arch eliminating, the possibilities for providing lifting facilities above the area immediately upstream of barrage gates.

It was finally decided to have portable caisson gate which would close off river and sçour sluice gate bays completely and would be movable from one gate bay to another gate bay. It would also operate under normal pond level conditions from 15th October to 15th April. The sketch is attached (Exhibit No.3). It would consist of tension type radial gate, having a boyant gate connected by parallel gate arms to a pivot beam. The gate, arms and pivot beam form integral structure and pivot beam transfers water load to piers through pivot wheels situated at either end. The whole integral structure is carried by pontoon. In this way the radial type gate is fitted on the crest at a distance of about 4.0 ft from the original gate which is removed by cutting it and new one of slightly different design is fixed. Instead of present lattice type girder, design which although economical in terms of steel, is expensive to fabricate and difficult to maintain. The new design adopted is fabricated of steel skinplate and plate girder with 7 drain holes (Exhibit No.4). In this way about 27 gates have already been replaced and the balance would be replaced in couple of years. In fact the target date for completion is 15th April 1991.

CONCLUSION

The sukkur Barrage gates were under operation for about 50 years when the accident occured. The main reason for failure as already stated was the corrosion of bracing member back bow string girder alongwith few compression members. Most of the steel work in lower third of river gates gets badly corroded due to combined process of silt abraision, aeration from water turbulence ad oxidation resulting from repeated immersion and removal from water. The corrosion takes place due to continuous operation of the gates..

"Stich in time saves nine" : It is suggested that close inspection of each member of barrage gate may be carried out each year and as soon as the metal thickness reduces by more than 20%, the particular member may be replaced. Alternatively, we should consider the life of gate as 50 years and try to replace them if number of members are corroded to 80% thickness. Lately corrosion resistant paints have also appeared in market and use should be made of them to increase the life of gate. This, at best, can be considered as adhoc measure and not a permanant solution in any case.

REFERENCE :

1. Sukkur Barrage gates Study, Final Report (1984) - Sir M.M.P. Ltd.
2. Various Reports from Irrigation & Power Department, Govt. of Sindh.

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