Load testing of one span of the third Godavari Bridge

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In accordance with the provisions of IRS concrete bridge, one complete span of the third Godavari Bridge was load tested to establish the behaviour of the bow-string arch under live load condition. The article describes load testing scheme and analyses the results of the test. The load test proved that the superstructure has the adequate capacity to carry the design load.

The first span of the third Godavari Bridge was proposed to be load tested for full live load in order to establish the predicted behaviour of the bow-string girder under live load conditions.

Load test scheme

The tie-girder is critical when the full span is loaded with live load and the arch is critical for unsymmetrical load which occurs when half the span is loaded with live load. Therefore, two types of load tests were proposed to be performed -- one with full span load with the live load and other half span loaded with the live load. The live load was proposed to be simulated by means of 24 jack loads (each jack 100t capacity) at every DINA hanger location. Therefore, at every DINA hanger location the jack loads were applied and in this manner 24 jacks, that is, 12 on down-stream side and 12 on up-stream side were loaded. The jacks were to be loaded precisely and simultaneously. The maximum loading time allowed was 60 minutes.

The jack loads are equivalent series of point loads applied at every DINA hanger location to induce deflection at the mid span, similar to the one that would have occurred, had the equivalent uniformly distributed load (EUDL) for bending moment acted.

The first DINA hanger is at 9,050mm from the bearing centre-line on either side and other DINA hangers are 6,900mm apart. Therefore, in proportion to the span that each DINA hanger supports the point loads are determined. The end jacks, that is, jacks at the first DINA hanger location (1A, 1B, 1C and 1D) were given a thrust of 402kN (for 100 percent live load) and the remaining jacks (20 nos.) were given 349 kN each. Thereby the total load for jacks came to (402 x 4) + (349 x 20) = 8,588 kN, Figure 1.

Twelve transverse steel beams (made of ISMB sections) were placed on the top of ballast retaining walls with the centre-line of beams matching with the centre-line of DINA hangers. The jacks were placed on the top of this steel beam. The jack reaction was attained by hanging kentledge load. The weight of kentledge carrying system is approximately 4t. Every two jacks were provided with one kentledge-carrying system. Each kentledge-carrying system contains approximately 85t load for a jack load of 2 x 35 t = 70 t for intermediate jacks (20 nos.) and 105 MT for a jack load of 2 x 41 = 84t end jacks (4 nos.). Hence, it was seen that the loads would not be off-loaded completely and that the loads would rest on ground throughout the load test. The kentledge loads loaded in the steel frames (12 numbers of such frames carry the kentledge loads at 12 locations) were connected to the small beam (on top of tie-girder) by means of Dy-widag bars (high tensile bars of capacity 42t each). The Dy-widag bars run through the holes provided in the bottom slab and the top slab and were anchored at the top in the small beams. The small beam carries, therefore, the load and the jack is placed below this small beam on the top of the transverse beam. The load, therefore, goes down to the ballast retaining wall directly which is very near to the web location. The ballast retaining wall is designed for this purpose also.

The load testing had to be started early in the morning to avoid influence of direct sunlight. The following schedule was maintained :

1. zero reading should take maximum time of 30 minutes

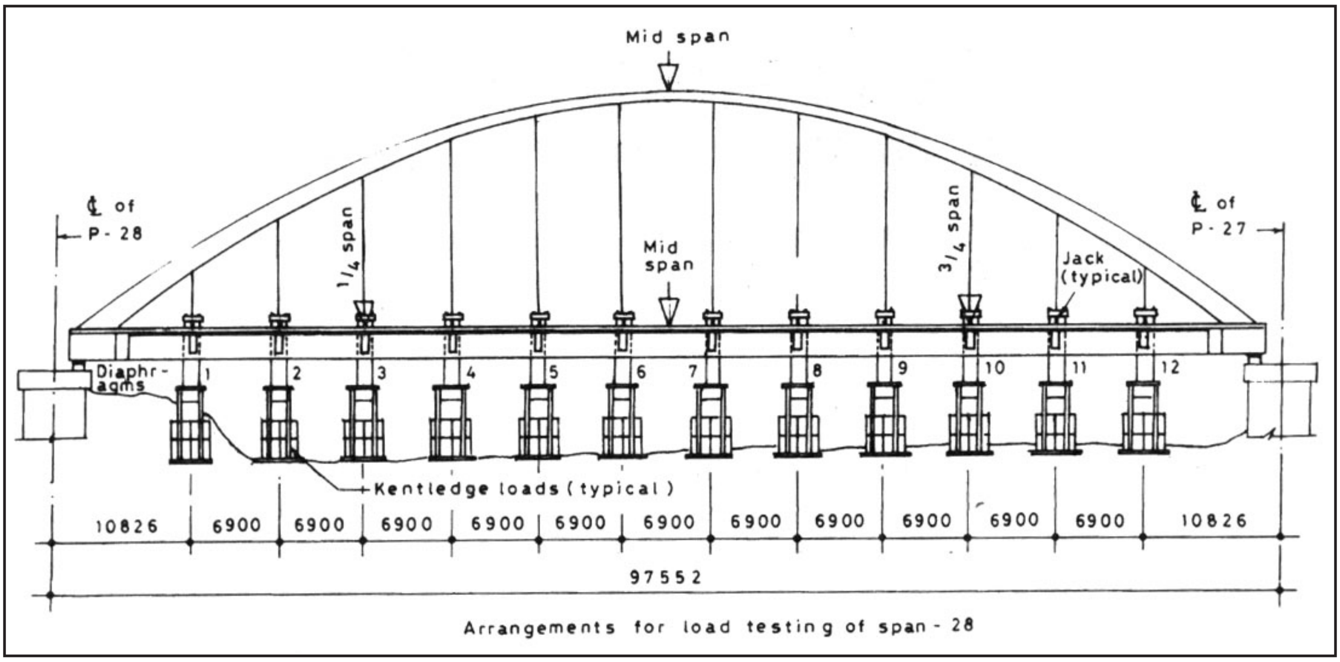

Figure 1. General arrangement for load testing span no. 28

2. loading steps should take maximum time of 60 minutes

3. the measurements taken after loading should take maximum 30 minutes

4. the unloading operation should take 30 minutes

5. the zero reading (after unloading is completed) should take maximum 30 minutes. Before starting actual loading the influence on the girder due to temperature variation with regard to the movement of arch and tie-girder is to be studied.

For a few days before the load test, the levels of arch points and the tie-girder points were monitored for 24 hours duly taking the temperature readings and the levels for every 2 hours. A graph was plotted for movement of arch points and movement of tie-girder points versus ambient temperature variation. This serves as reference whenever the movement of points occur due to load combined with the temperature variation. In Session-4 the load is to be kept for 24 hours and, therefore, the temperature effect will come into play. For calculating the deflection of the various points owing only to the live loads the deflection due to temperature variation needs to be deducted.

The soffit points were monitored by the deflection dial gauge having 0.01mm accuracy. The side points were observed by theodolites. The dial gauges are to be placed on the portal beams (3 numbers) consisting of steel beam resting on steel cribs as the supports. The side points are to be monitored by theodolites placed one on up-stream side and other on down-stream side.

Also, the bearings points on either side of pier no.28 and pier no.27 were monitored for settlement if any, due to load test.

Methodology

A survey scheme was followed to establish various reference points to be observed for vertical deflection on the tie-girder and on the arches. First, the actual mid span point was established and then 1/4th span, 3/4th span were established on the ground with the help of all station instrument (Electronic theodolite fused with electronic distomat). These ground points were transferred to the tie-girder soffit and sides and to the arches for observation.

The soffit of tie-girder was monitored with the help of dial gauge, erected on portal frames. The sides of the tie-girder and the arch reference points were observed by theodolite and all station instrument.

Arrangements made during the load testing

In order to ensure that all the jacks were loaded simultaneously, it was proposed to load the jacks in increments of 50kN. Therefore, seven increments of 50kN have been followed till the end jack load reaches 350 kN and intermediate jacks to 300kN. Then, an increment of 20kN followed to reach the final jack loads of 402 kN for end jacks and 349 kN for intermediate ones. The jacks have been calibrated by the already calibrated proving ring (of 200 t capacity) in a specially-fabricated rig at site.

The 24 jacks were proposed to be operated by 12 pumps which were manually operated. At every pump location one engineer/supervisor was proposed to man along with railway representatives at every 3rd location. Each group was given one red flag, one green flag, one whistle, torch light etc. Also one control room was set up in the mid span on the ground where the fixed station wireless set was set up and the hand-held walkie talkie sets were provided to personnel on the arch and on the piers.

For starting the loading operation, control room announced through the PA system to all the groups to start the first increment of the load. After completion of the first increment of load each group would raise green flag, indicating successful completion of the first increment. They would raise red flag if any trouble arose. After completion of the first increment by all the 12 groups, approval to start second increment was given duly announcing again by control room to all the 12 groups. Similarly, all the increments were completed till the required jack loads were reached.

A total of 24 jacks were needed for the load testing; however, 4 jacks were kept as standby so that in case any leakages occurred during the sustained load of 24 hours or otherwise, the affected jacks could be tackled in the manner stated below:

A stool-type arrangement consisting of steel ISMB sections was made. This stool was placed by the side of the transverse beam and on the top of these stools 45t capacity jacks were placed which would lift the small beam (which carries the load directly). This arrangement was done on either side of the transverse beam so that the small beam could be lifted symmetrically by two jacks which would relieve the affected jack. Afterwards the affected jack could be taken out. However, no such instance of jack failure took place throughout the load test.

Reference marks were made on the pier top, one on down-stream side and another on up-stream side of each pier. These points were marked on pier no. 28 and pier no. 27 to monitor the pier settlement during the load testing, if any. The two points would show the tilt during the load test.

Loading details of the tie-girder

1. The structural dead load = 17,744 kN
2. The superimposed dead load which consists of footpath and track load = 6,871 kN
3. Jack loads = 402 x 4 plus 349 x 20 = 8,588 kN

Total load on the girder at the time of load test = 33,203 kN

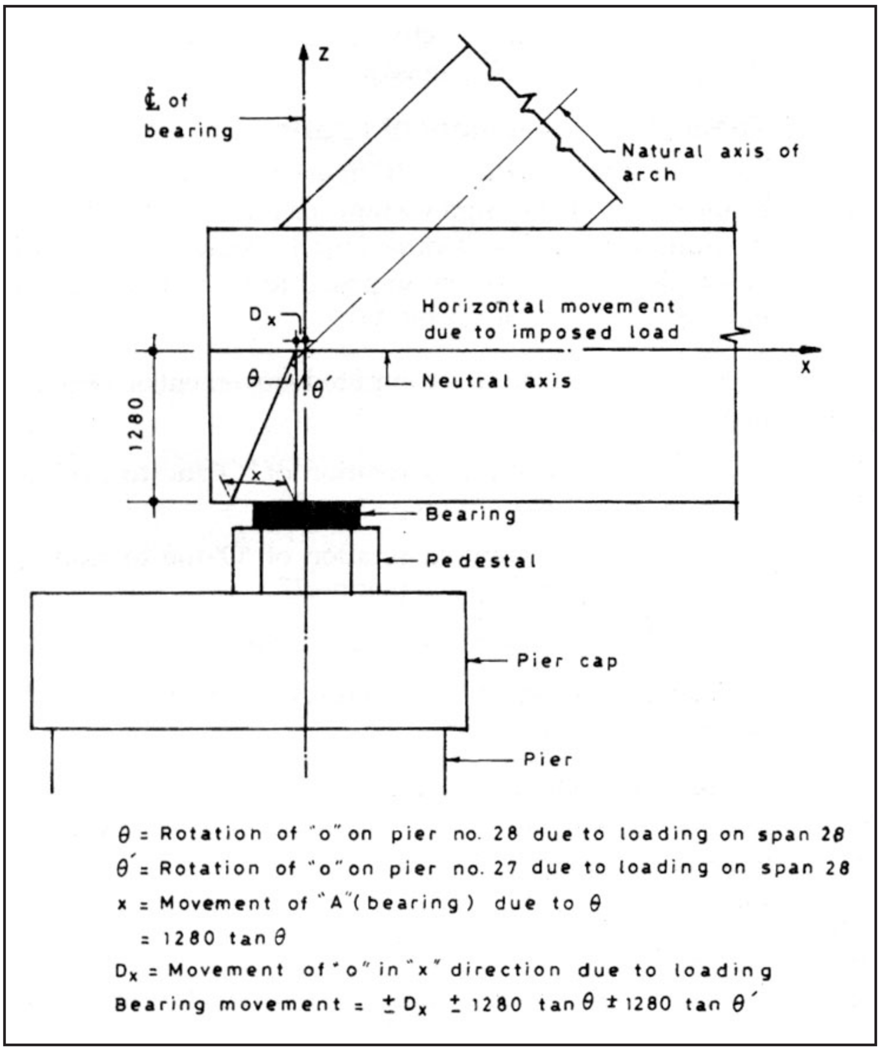

Figure 2. Movement of bearings on pier no. 28 (free end) during loading and unloading

Results of load test

The load test was conducted from January 17 to 20, 1995. First session was started on January 17, 1995, and in this session full span was loaded with 50 percent and 100 percent live load and the readings were taken at 50 percent live load and 100 percent live load stages. Unloading was done immediately and final readings were taken. Before loading the span, the initial zero-reading was also taken for reference.

Second session was executed on January 18, 1995. In this session half span towards Rajahmundry side was loaded with 50 percent live load and 100 percent live load by loading the DINA hangers 1 AD to 6AD. Like the first session here also readings were taken before starting the loading, after reaching 50 percent live load value, after reaching 100 percent live load and after unloading. The unloading was done immediately.

Third session was executed on January 19, 1995 and in this session the Kovvur half of the span was loaded duly loading the Kovvur side of the DINA hangers (that is, IBC to 6 BC). The loading was done for 50 percent live load and 100 percent live load as in second session and readings were taken as in second session.

Fourth session was executed on January 19, 1995 at 12.14 hours. In this session the full span was loaded upto 100 percent live loaded directly without taking any

Table 1. Comparison of deflections

Sr. no.	Location of point	Loading stage, percent of live load	Actual average deflection, mm	Computed deflection, mm	Actual deflection as of computed deflection, percent
I.	**Full span loaded with 50 percent live load and 100 percent live load**				
1.	Tie-girder 1/4th span and 3/4th span	50	8.32	10.40	80
2.	Tie-girder mid point	50	11.47	14.40	80
3.	Arch mid point	50	5.00	5.60	90
4.	Tie-girder 1/4th span and 3/4th span	100	18.92	20.80	91
5.	Tie-girder mid point	100	27.38	28.80	95
6.	Arch mid point	100	11.50	11.20	102
II.	**half span load on Rajahmundry side**				
1.	Tie-girder 1/4th span	50	11.95	16.00	75
2.	Tie-girder 3/4th span	50	-4.72	-7.00	67
3.	Tie-girder mid point	50	4.66	5.00	93
4.	Arch mid point	50	1.50	2.00	75
5.	Tie-girder 1/4th span	100	25.55	32.00	80
6.	Tie-girder 3/4th span	100	-8.87	-14.00	63
7.	Tie-girder mid point	100	9.86	10.00	99
8.	Arch mid point	100	3.50	4.00	87
III.	**Half span load on Kovvur side**				
1.	Tie-girder 1/4th span	50	-3.40	-7.00	49
2.	Tie-girder 3/4th span	50	9.59	16.00	60
3.	Tie-girder mid point	50	3.11	5.00	62
4.	Arch mid point	50	1.50	2.00	75
5.	Tie-girder 1/4th span	100	-8.59	-1400	62
6.	Tie-girder 3/4th span	100	25.03	32.00	78
7.	Tic-girder mid point	100	9.28	10.00	93
8.	Arch mid point	100	3.50	4.00	87
IV.	**Full span : 100 percent of live load retained for 24 hours**				
1.	Tie-girder 1/4th span and 3/4th span	100	19.47	20.80	94
2.	Tic-girder mid point	100	27.18	28.80	94
3.	Arch mid point	100	10.50	11.20	94
	Average = 81 percent				

reading at 50 percent live load value. However, initial reading was taken before loading. Also, readings were taken after loading was over. The 100 percent live load was sustained for 24 hours. The readings were taken for every 2 hours thereafter upto 12.30 hours of January 20, 1995, when 24 hours period was over. Thus the span was off-loaded by 12.30 hours of January 20, 1995. The final reading was taken after unloading. Since, the recovery was immediate and complete no more readings were taken.

The readings were taken by means of a theodolite on the sides of the tie-girders and the arch points. For this purpose one theodolite (T-2) was set on down-stream side and an all station instrument was set on up-stream side. These theodolites were used to observe the I /4th span point, mid-span point, 3/4th span point on the sides of the tie-girder mid point on the arches. The other points on the arch (12 DINA hanger location points) were observed from the old bridge by means of another theodolite. The soffit of the tie-girder was monitored by means of dial gauges including the bearing locations. The dial gauge readings were compared with the theodolites readings. Close correlation was found between the two readings. However, the theodolite readings were found more accurate.

Remarks

In general the observed deflection of the points of tie-girder and arch confirm the computed deflections.

The actual characteristic strength of concrete (f_{ck}) based on cube test results, was approximately 53 N/mm^2 (calculated for span no.28 only) for span no.28. Also, the age of concrete of arch is approximately 3 years and tie-girder 2 years. As per IS:456 code the increase in strength of concrete for 2-3 years of age is 20 percent. So, the actual deflection should be (45/53 x 100) = 85 percent of the calculated deflection. However, the actual f_{ck} value which is based on the cube-test results does not reflect the actual value of f_{ck} for the structure, since the cubes are always cured in more ideal conditions than the actual structure (particularly an arch which is a sloping structure). Hence, the actual deflection could be between the computed deflection and 85 percent of the computed deflection and that can be considered as a satisfying result. A comparison of deflections observed at different locations is presented in Table 1.

If the average of all the above averages are taken then the net average works out to 81 percent of the computed deflection for the complete span, Table 1. Therefore the requirement of results falling between 85 percent to 100 percent of the computed results is satisfied with some of the results actually falling below 85 percent of the computed results -- indicating better strength of the structure. This indicates that the actual strength of the tested span is quite adequate.

Theoretical movement of bearing on pier-28

The movement of point 'O' (Origin) in X-direction, Figure 2, can be taken from the design volume-1B for different load-cases. In addition to the DX (X-direction) movement of 'O', rotation of 'O' also has to be superimposed to find total X-direction movement of Bearing (Point A).

For example, DX is the computed movement of 'O' (Origin) in X-direction.

O = computed rotation of 'O'due to loading in radians on pier no.28
O' = computed rotation of 'O'due to loading in radians on pier no.27.
X = 1280 tan 8 or 1280 tan ø'.

So, net movement of point A due to loading = $\approx$ DX $\approx$ 1280 tan θ $\approx$ 1280 tan θ'.

For full span 100 percent live load

DX (computed value of movement of support in X-direction at neutral axis level - load case-XI of design volume 1B) = 3.28 mm.

Rotation of X-section of the support at the neutral axis level -

load case-XI of design volume 1B(θ) = 0.000884 radian = 0°3′2″

The same θ is applicable for both ends since loading is symmetrical.

So, computed movement of support at the bottom (bearing movement)

= - (3.28 + 2 x 1280 tan 0°3'2")
= - (3.28 + 2 x 1.13) = - 5.54 mm (away from span)

Half span 100 percent live load on Rajahmundry/Kovvur side DX (computed value of movement of support in X-direction at neutral axis level - load case-XI of design volume 1B) = -1.34mm (away from span).

Rotation of X-section of the support at the neutral axis level - load case-XI of design volume 1B(0) = 0.001951 radian on loaded side support.
= 0°6'42".
= 0.001053 radian on other side support
= 0°3'37'.

So, computed movement of support (bearing movement)
= -1.34 - 1280 tan 0°6'42" + 1280 tan 0°3'37″
= -1.34 - 2.50 + 1.35
= -2.49 = -2.50mm (away from span).

Actual bearing movement on pier no. 28

During loading of the span the bearings on pier no.28, which are free to move in the longitudinal direction, have undergone movement. The bearings have moved upward from the span and the readings of the bearing movements are as follows.

Sr. no.	Load case, percent of live load	Net bearing movement, mm	Computed movement, mm
1.	Full span 50	2.00	2.77
2.	Full span 100	4.50	5.54
3.	Half span 50 on Rajahmundry side	1.00	1.25
4.	Half span 100 on Rajahmundry side	2.50	2.50
5.	Half span 50 on Kovvur side	1.00	1.25
6.	Half span 100 on Kovvur side	2.00	2.50
7.	Full span load for 24 hours	4.50	5.54

Therefore, it is seen that the actual bearing movements are either as per the computed bearing movements or less than these. The bearing moves outward because of the arch thrust that comes into play due to loading of the tie-girder. Thus, the prestress force in the tie-girder is reduced resulting into extension in the tie-girder. However, there will be no cracks in the tie-girder under this condition since the tie-girder is still left with some amount of prestress in it.

Since the pier settlement is very less and, therefore, the corrections also will be very less. The actual deflection for the tie-girder, which was 94 percent of computed deflection without correction, will become 89 percent with correction. Similarly, for arch mid point with 94 percent of computed deflection without correction becomes 85 percent with correction.The readings were taken for 24 hours and during this period the change in level in both tie-girder and arch was noticed to be of the order of 1 mm to 2 mm. Since the effect of temperature on deflection was not appreciable, no corrections were made on account of temperature variation. The temperature variation between loading on January 19, 1995 and unloading on January 20, 1995 was 3°C.

Table 2. A comparison of expected and actual deflections

Sr. no.	Date	Description	DINA hanger No.	Theoretical force in the langer, kN	Theoretical extension of the hanger mm	Actual extension of hanger mm	percent
1.	January 17, 1995	Full span loaded-100 percent live load	6A, 6B, 6C, 6D	338	17.74	15.63	88
			3A, 3B, 3C, 3D	335	13.01	13.12	101
2.	January 18, 1995	Half span loaded - 100 percent live load					
		Loaded side	6A, 6D	136	7.14	5.93	83
		Other side	6B, 6C	133	6.98	5.78	83
		Loaded side	3A, 3D	150	5.82	4.61	79
		Other side	3B, 3C	128	4.97	5.10	103

Extension of DINA hanger cables due to live load

When the live-load is applied on the tie-girder (running deck), the DINA hangers elongate depending on the position of live load. The extent of elongation depends on the load that any particular DINA hanger shares. The extension of DINA hangers can be calculated by calculating the deflections of arch and the tie-girder at hanger locations.

A comparison of expected deflections and actual deflections at the third DINA hanger and sixth DINA hanger which are critical from design point of view is given in Table 2.

Conclusion

In view of the innovative nature of the design of this bridge, being built for the first time in India, it was crucial to establish the predicted behaviour of the girder by conducting a load test. The load test was also necessary to establish the efficacy of adopting the various codes and procedures in the design and also to establish the level of quality control measures. As has been brought out in this article, the behaviour of the bow-string girder has been quite satisfactory from various points of view, most important parameter of behaviour being comparison of actual deflection of various points with the computed deflections. Also, the behaviour of bearings and the DINA hangers was studied and as brought in the article, the same was found to be quite satisfactory.

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