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ANALYSIS OF THE CAUSES OF DISTRESSES IN A PRE-STRESSED CONCRETE BRIDGE

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ABSTRACT

In recent years, distress has been observed in several PSC structures, which had a latent weakness due to lack of good detailing, improper design, adverse climate, and absence of skilled work man to manufacture and place good quality concrete. In some cases there would be multiple interacting events to cause distress. Common interactive causes are corrosion combined with poor quality of construction or improper design with heavy load etc. This paper describes a PSC bridge of balance cantilever-cum-suspended span type, distressed due to improper design and poor quality of construction. Stresses at cracked section have been calculated. The nature of the failure, location of crack and cause of distress has been discussed.

Keywords: doomed bridge, PSC bridge failure, improper design, balance cantilever bridge, cracks.

INTRODUCTION

Bridges are basic infrastructure, expected to be reliable by all modern industrial societies. Bridge use and construction have evolved greatly in the last 100 years. Quality materials, adequate design, and good manufacturing techniques are assumed today. In addition, we assume that bridges receive periodic inspections with regular maintenance actions. Before building a bridge, it is important to establish a good understanding of the weak points of bridge design, and the reasons for bridge failure. This knowledge helps focus on the key elements of the design. Even one high stress event on a key part of a bridge design can often lead to immediate or eventual failure. This Bridge is situated on the upstream of Dam on the river. The bridge was constructed hardly 5 years back. This is a PSC bridge of balance cantilever-cum-suspended span type, supporting 26.7m suspended span. This type of arrangement is very common but its design and construction should be a matter of great importance. After few months of allowing traffic the portion of the supported span near the pier had cracked, cantilever portion had sagged and the bridge was closed to traffic.

The bridge

The bridge is a high level, balance cantilever-cum-suspended span deck Type Bridge with sixteen spans resting on hollow circular piers, supported on well and open type foundations. A common structural unit consists of 44.5m pre-stressed concrete box with 12.5m cantilever on one side and 9.5m cantilever on the other side. A suspended span of 26.7 m in length resting on the tip of cantilevers from both sides. The suspended span has pre-stressed concrete three girder system. Some supported spans are larger than 44.5m Figure-1.

Table-1. The salient features of bridge.

1	Length of the bridge	702 m
2	Deck	Overall width of 8.4 m and roadway of 7.5 m.
3	Bearings	Elastomeric and PTFE
4	Wearing Coat	RCC Wearing Coat
5	Piers	16 nos. hollow circular piers with diaphragms
6	Formation level	RL 351.5 m
7	Soffit level	RL 348.425 m
8	H.F.L. (considered in the design of the bridge	RL 345.725 m
9	L.W.L. (considered in the design of the bridge)	RL325.315 m
10	Foundation	P1, P2, P3 are open type and P4 to P16 are well type. Deepest foundation level RL315m

Observations

The author, along with the team of Engineers from the concern department visited the site. The Bridge was inspected by boat from below; it was also inspected critically from the road. These observations are recorded as follows:

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- The deck is supported on 2 Piers and cantilevered on both sides with a suspended span supported on cantilever Figure-2.
- Supported deck on piers is 44.5m (main span) and cantilever is 12.5m on abutment side and 9.0m on other side Figure-10.
- Suspended span has 3 pre-stressed girders and deck slab above Figure-3.
- Depth of water is 20m at present. Maximum water level is 2m above the present water level.
- The cantilever on pier P10 towards P11 has sagged, therefore the suspended span has also deflected at that end. Figure-10.
- There was a wide through crack in the main span supported between pier P9 and P10 just left side (Jigna side) of pier P10. Because of this cantilever on Barhi side has sagged Figures 2, 6 and 7.

Figure-1. General view of the bridge.

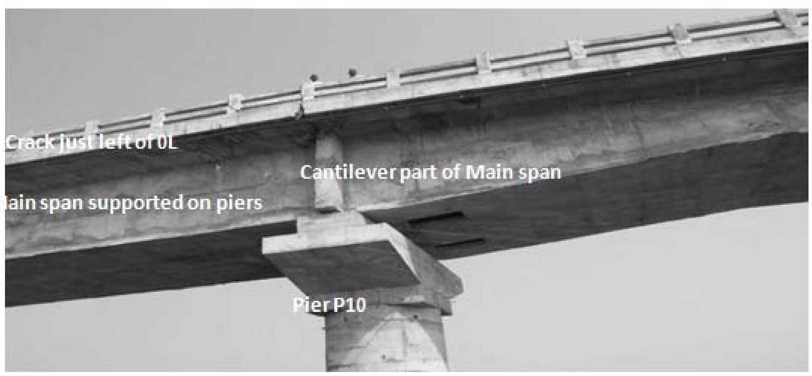

Figure-2. Location of crack view from bottom.

Figure-3. End cross girder of suspended span view from bottom.

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Figure-4. Honey combing at soffit level.

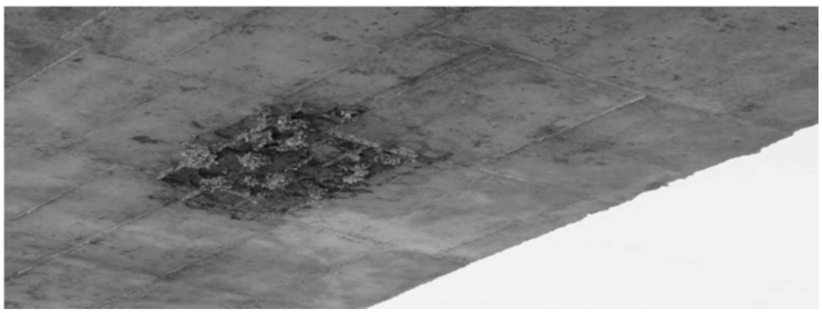

Figure-5. Shuttering has not removed view from bottom.

Figure-6. Location of crack and curtailment of cable number VIII view from bottom.

- The rock level is reported to vary from R.L.315.000 to R.L.328.000. Thus, founding levels are varying.
- Cross girder of one suspended span appears to be cracked and not constructed in alignment (Figure-3).
- Cross girders of other suspended span are damaged and steel is exposed. The sides of box deck appear to have been honeycombed, and are repaired. At many other locations also honeycombing is observed (Figure-4).
- There are cracks at the end of the span and at many places there is damage of concrete surface below the soffit.
- At some locations the form work done prior to casting is observed to be stacked at the locations (Figure-5).
- Concrete wearing coat is found to be damaged in several places. Asphaltic wearing coat is merely 20mm.
- The gap between suspended span is open at one end and closed on the other side.
- Open type expansion joints are provided and these are damaged almost at all the expansion joint locations.
- The Water spouts were observed not to be done properly and not projecting 200mm below the soffit.
- The kerb is found to be damaged at places.

Small damages/ honeycombing within the structural elements reflect badly on the quality of structural elements and workmanship.

As an overall view the workmanship and quality monitoring are observed to have a scope of improvement and such lacunas during construction reflect on the serviceability of the structural elements.

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The analysis

The main span consists of pre-stressed concrete box supported on piers with cantilever on both sides. Depth of cantilevers is more at support lesser at tip. At the tip of cantilever there is a suspended span which has three pre-stressed concrete girder system and deck slab. The Bending moment and the stresses due to Dead load (DL) (due to supported span, suspended span, cantilever span), Live load (LL), superimposed dead load (SIDL) at section just left and just right of 0L (pier P10) are calculated below. Cross sectional Properties are as per the original design calculation.

Calculation of stresses just left and right side of 0 L section (pier P10).

Dimensions and properties of different spans

Suspended span on right side

Type	PSC T-beam Girder with bottom bulb, RCC deck
Overall span	26.7m
Effective span	26.1m
Overall depth	2 m
Deck thickness	225mm
Number of ends cross girder numbers	400mm thick, two
Number of intermediate cross girder	75mm thick, three numbers
Rib thickness	275mm and 475 mm at end up to 1.2m
Dead Load reaction from Suspended span	176.55 tonnes (t)

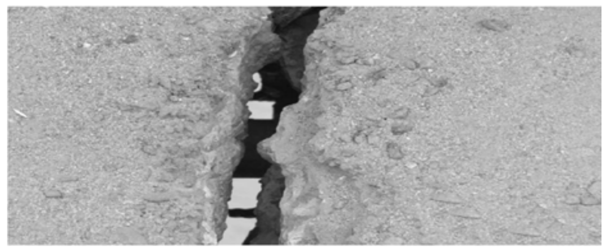

Figure-7. Reinforcement seems to be sheared off in the cracked portion view from top.

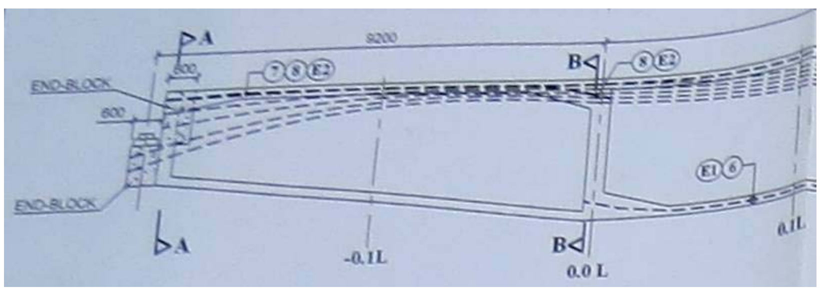

Figure-8. Portion of working drawing of main span showing curtailment of cable VIII at 0L.

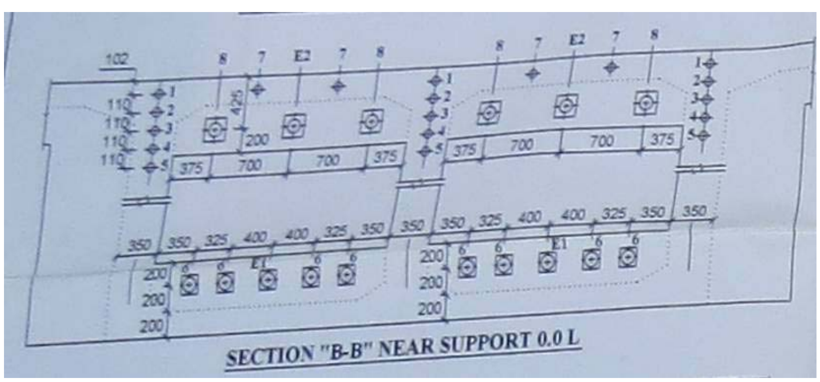

Figure-9. Portion of working drawing showing cross section of main span and curtailment of cable VIII at 0.

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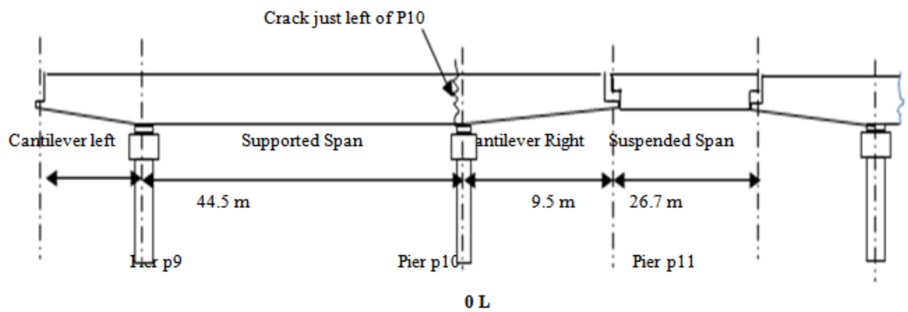

Figure-10. Span arrangement between pier P10 and P11.

Moment at the face of cantilever (0L) 176.55 x 9.2 = 1624.26 tonne meter (tm)

Cantilever span on right side

Type	Two rib PSC Box
Over all span	9.5m
Effective span	9.2m
Depth of cantilever	as per table 2
Moment at 0L due to self weight of cantilever	602.38 tonne meter (tm)

Table-2. Properties at different sections (right side from 0L).

Distances from 0L in (mm)	**Overall depth in** (mm)	**Thickness of soffit in** (mm)	**Thickness of rib in** (mm)
-9500	875	200	850
-8900	2000	200	400
-8300	2067.4	200	400
-7700	2134.8	200	300
-4450	2500	200	300
-2400	2730.3	200	300
-1800	2797.8	200	300
0	3000	200	350

Section at 0L

Area of cross section at 0 L = 57867cm2
Section modulus at top Zt at 0 L = 55x10^5 cm3
Section modulus at bottom Zb at 0 L = 42.82 x 10^5 cm3
Distance of C.G. From top = 131.33 cm

Calculation of stresses due to DL, LL, SIDL and Prestressing at just right of 0L section

Due to dead load

i) Moment due self weight of cantilever = -602.38 tonne meter (tm)

ii) Moment due self weight of Suspended span = -1624.3 tm

iii) Moment due self weight of Main span = 0 tm

M/Z stress at top = -40.484 kg/cm^2
M/Zb stress at = 52.0001 kg/cm^2

Due to superimposed dead load

Kerb below Railing	2 x 0.45 x 0.3 x 2.4	=	0.684 t/m
Railing	2 x 0.15	=	0.3 t/m
Wearing Coat	7.5 x 0.075 x 2.4	=	1.35 t/m
Total		**=**	**2.298 t/m**

i) Moment due self weight of cantilever = 2.298x 8.9x4.45 = -91.02 tm

ii) Moment due self weight of Suspended span = 2.298 x 26.1 x0.5 x 9.2 = -275.89 tm

iii) Moment due self weight of Main span = 0 tm

M/Zt stress at top = -6.6711 kg/cm^2
M/Zb stress at = 8.56866 kg/cm^2

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Due to live load

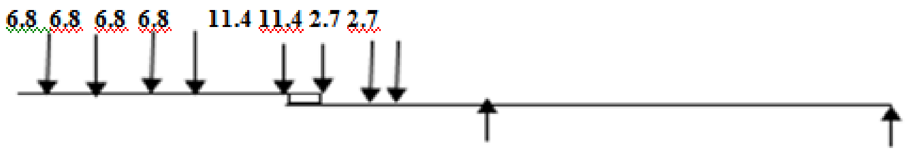

Figure-1a. Live load arrangement of IRC class A loading.

For this condition live load moment at 0 L = -999.138 tm

M/Z stress at top = -18.166 kg/cm^2

M/Zb stress at = 23.3334 kg/cm^2

Total moment due to DL = -2593.6 tm

Total moment due to LL = -999.14 tm

Due to prestressing (As per original calculation)

Detail of the prestressing cables provided is shown in the Table below.

Table-3. Number of cables and strands per cable (As per working drawing).

Cable group	Number of cables	Number of strands per cable	Total of strands per cable
I	3	8	24
II	3	8	24
III	3	8	24
IV	3	8	24
V	3	8	24
VI	4	10	40
VII	4	10	40
VIII	4	8	32

Prestressing force after relaxation loss as per the original design calculation and Center of gravity (C.G.) of prestressing force is as per the Table below:

Table-4a. Prestressing force and its center of gravity (C.G.)

Cable number	Number of cables	Number of strands per cable	Total number of strands	C.G. of cables to the top of deck D	DxN	Stress (kg/mm^2) at 0L after relaxation loss	Force in tone (t)	FxD
1	2	3	4	5	6	7*	8	9
					4 x 5		2x3xA**x7	5x8
1	3	8	24	102	2448	121.26	287.24	29298.6
2	3	8	24	212	5088	121.32	287.38	60925.2
3	3	8	24	322	7728	121.43	287.64	92621.2
4	3	8	24	432	10368	125.88	298.18	128816
5	3	8	24	542	13008	125.78	297.95	161488
6	8	5	40	2600	104000	113.57	448.37	1165773
7	4	10	40	112.5	4500	120.86	477.16	53680
8	4	8	32	425	13600	104.32	329.48	140031
			232		160740		2713.4	1832632

* as per original calculation

** area of one strand

C.G. of cable to the top of deck at 0L =∑6 / ∑4 =160740/232 = 692.84 mm

C.G. of force to the top of deck at 0 L =∑9 / ∑8 =1832632/2713.4= 675.40 mm

Stresses due to pre stress at just right of the pier P10 or 0L section are calculated inTable-4b.

Table-4b. Stresses due to pre-stress just right of 0L section.

	Yt Distance of C.G. from top	**Area of cross section at cantilever support** (cm^2)	**C.G. of force to the top of deck in** (cm)	**C.G. of cable to the top of deck in** (cm)	**Eccentricity (Ecc.) of cables to the top of deck**	**Ecc. of force to the top of deck**	**Initial pre-stress Force t**	**Direct stress** (kg/cm^2)
	10	11	12	13	14	15	16	17
					10-13	10-12	∑8	16/11
0 left	131.33	57866.8	67.54	69.284	62.0455	63.7	2713.4	46.8907
0 right	131.33	57866.8	67.54	69.284	62.0455	63.7	2713.4	46.8907

Moment due to initial pre stressing (IP) force is given below in Table-4c. Eccentricity (Ecc.) of forces is taken from the column number 15 of Table number 4b above.

Moment due to Initial pre-stress (IP) force is calculated inTtable-4c.

Table-4c. Moment due to Initial pre-stress (IP) force.

	Initial pre-stress Force t	**Ecc. Of force to the top of deck**	**Moment due to IP force tm**
	18	19	20
	∑8	15	18 x 19
0 left	2713.4	63.7*	1683.6
0 right	2713.4	63.7*	1683.6

*In design in place of 63.79, 62.045 has been taken by mistake
Stresses due to initial pre stress at top and bottom is calculated and presented in Table below in Table number 4d

Table-4d. Initial pre stress at top and bottom.

	Zt x10^5 in (cm^3)	**Zb x10^6 in** (cm^3)	**Moment due to IP force tm**	**Ft bending top in** (kg/cm^2)	**Fb bending bottom in** (kg/cm^2)	**Direct stress** (kg/cm^2)	**Initial pre-stress Top in** (kg/cm^2)	**Initial pre-stress bottom in** (kg/cm^2)
	21	22	23	24	25	26	27	28
			20	23/21	23/22	17	24+26	25+26
0 left	55	-42.82	1683.6	30.612	-39.319	46.8907	77.502	7.57154
0 right	55	-42.82	1683.6	30.612	-39.319	46.8907	77.502	7.57154

All the losses considered in design is 16.94 kg/mm^2, considering the same and loss of moment and final moment after loss is calculated in Table-4e and 4f respectively.

Table-4e. Stresses after losses.

	Total number of strands	**Loss of stress in** (kg/mm^2)	**Loss of force in t**	**Yt** (cm)	**Ecc. of cable from top of deck** (cm)	**Loss of moment in tm**
	29	30	31	32	33	34
			29x30xA	10		31x(32-33)
0 left	232	-16.94	-387.9	131.33	69.2845	-240.67
0 right	232	-16.94	-387.9	131.33	69.2845	-240.67

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Table-4f. Final Pre-stress moment after loss.

	Initial pre-stress Force in t	Loss of force	Final pre-stress Force after loss in t	Initial pre-stress Moment tm	Loss of Moment in tm	Final Pre-stress Moment after loss in tm
	35	36	37	38	39	40
	∑8	31	35+36	20	34	38+39
0 left	2713.41	-387.90	2325.51	1683.65	-240.67	1442.97
0 right	2713.41	-387.90	2325.51	1683.65	-240.67	1442.97

Pre-stressing stress in top and bottom after loss is calculated below

Table-4g. Pre-stressing stress after loss in top and bottom.

	Area (cm^2)	Zt x10^5 in (cm^3)	Zb x10^6 in (cm^3)	Direct stress after loss (kg/cm^2)	Ft bending after loss top in (kg/cm^2)	Fb bending after loss bottom in (kg/cm^2)	Pre-stressing stress after loss Top in (kg/cm^2)	Pre-stressing stress after loss bottom in (kg/cm^2)
	41	42	43	44	45	46	47	48
	11	21	22	37/41	40/42	40/43	44+45	44+46
0 left	57866.8	55.00	-42.82	40.19	26.24	-33.70	66.42	6.49
0 right	57866.8	55.00	-42.82	40.19	26.24	-33.70	66.42	6.49

Dead load and Live Load moments will give tension on top fibers. Stresses due to dead load (D.L.) and live load (L.L) at top and bottom are calculated below in Table-4h.

Table-4h. Stresses due to dead load and Live Load at top and bottom.

	All dead load moments in tm	All live load moments in tm	D.L. + L.L. moments	Zt x10^5 in (cm^3)	Zb x10^6 in (cm^3)	DL and LL stress in Top in (kg/cm^2)	DL and LL stress in bottom in (kg/cm^2)
	49	50	51	52	53	54	55
			49+50	21	22	51/52	51/53
0 left	-2593.6	-999.1	-3592.7	55.00	-42.82	-65.3	83.90
0 right	-2593.6	-999.1	-3592.7	55.00	-42.82	-65.3	83.90

Prestressing stress after loss plus stress due to D.L. and L.L. at top and bottom are calculated below in Table-4i.

Table-4i. Final stress at top and bottom.

	Pre-stressing stress after loss Top in (kg/cm^2)	Pre-stresssing stress after loss bottom in (kg/cm^2)	stress due to DL and LL load at top (kg/cm^2)	stress due to DL and LL at bottom (kg/cm^2)	Final stress top (kg/cm^2)	Final stress bottom (kg/cm^2)
	56	57	58	59	60	61
	47	48	54	55	56+58	57+59
0 left	66.4	6.5	-65.3	83.9	1.1	90.4
0 right	66.4	6.5	-65.3	83.9	1.1	90.4

Max Stress in flexural compression = 90.391 < 118.96 Kg/Cm^2 for M35
Max Stress in flexural tension = 1.102 < 0 Kg/Cm^2 (as per IRC18 2000)

Calculation of stresses due to DL, LL, SIDL, pre-stressing at just left of 0L section

Now considering the section just left of the above section i.e. 0L. Stresses Produced by dead load and live load moments at the top and bottom will nearly be equal to the same as at 0L i.e. -65.3 kg/cm^2 and 83.9 kg/cm^2 respectively (column 58 and 59 of Table-4).

The cable number 8 has been curtailed at 0L, so it is not available at the section just left of the section at 0L i.e. now only 200 strands are available, there are

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deficiency of 32 strands. In that case the stresses at just left of 0L due to External Stresses induced by Prestressing force after considering all losses at top and bottom will be

Due to pre-stressing

Stresses due to pre-stress just left of 0L or P10 will be different than the value at just right of 0L because cable number 8 have been curtailed at 0L and it is not available at section just left of 0L. Value of stresses at just left of 0L is calculated below in Table-5a.

Table-5a. Stresses due to pre-stress just left of 0L section.

Cable number	Number of cables	Number of strands per cable	Total number of strands	C.G. of cables to the top of deck D	DxN	Stress kg /mm^2	Force in t	FxD
1	2	3	4	5	6	7*	8	9
					4 x 5		2x3xA**x7	5x8
1	3	8	24	102	2448	121.26	287.24	29298.6
2	3	8	24	212	5088	121.32	287.38	60925.2
3	3	8	24	322	7728	121.43	287.64	92621.2
4	3	8	24	432	10368	125.88	298.18	128816
5	3	8	24	542	13008	125.78	297.95	161488
6	8	5	40	2600	104000	113.57	448.37	1165773
7	4	10	40	112.5	4500	120.86	477.16	53680
8	4	0	0	425	0	104.32	0	0
			200		147140		2383.9	1692602

C.G. of cables to the top of deck = 735.7 mm
C.G. of force to the top of deck = 710.01 mm
Initial pre stressing force and stresses at just left of 0L section is given below in table 5b.

Table-5b. Initial pre stressing force and stresses.

	Yt	Area of cross section at cantilever support (cm^2)	C.G. of force to the top of deck	C.G. of cable to the top of deck	Ecc. of cables to the top of deck	Ecc. of force to the top of deck	Initial pre-stress Force t	Direct stress (kg/cm^2)
	10	11	12	13	14	15	16	17
					10-13	10-12	∑8	16/11
0 left	131.33	57866.8	71.001	73.57	57.76	60.3295	2383.9	41.1969
0 right	131.33	57866.8	71.001	73.57	57.76	60.3295	2383.9	41.1969

Moment due to initial pre stressing force is calculated in Table-5c

Table-5c. Moment due to initial pre stress force.

	Initial pre-stress Force t	Ecc. of force to the top of deck	Moment due to IP force tm
	18	19	20
	∑8	15	18 x 19
0 left	2383.9	60.3295	1438.2
0 right	2383.9	60.3295	1438.2

Stresses at top and bottom due to initial pre stressing force is calculated and presented in theTtable-5d below.

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Table-5d. Initial pre stress at top and bottom.

	Zt x10^5 in (cm^3)	**Zb x10^6 in** (cm^3)	**Moment due to IP force tm**	**Ft bending top in** (kg/cm^2)	**Fb bending bottom in** (kg/cm^2)	**Direct stress** (kg/cm^2)	**Initial pre-stress Top in** (kg/cm)	**Initial pre-stress bottom in** (kg/cm^2)
	21	22	23	24	25	26	27	28
			20	23/21	23/22	17	24+26	25+26
0 left	55	-42.82	1438.2	26.149	-33.587	41.1969	67.346	7.60946
0 right	55	-42.82	1438.2	26.149	-33.587	41.1969	67.346	7.60946

losses will reduce at this section as cable number VIII is not available
= 15.405 kg/mm^2
Loss of the moment due to loss of per stressing force is calculated in Table-5e.

Table-5e. Loss of the moment.

	Total number of strands	**Loss of stress**	**Loss of force in t**	**Yt cm**	**Ecc. of cable from top of deck** (cm)	**Loss of moment in tm**
	29	30	31	32	33	34
			29x30xA	10		31x(32-33)
0 left	200	-15.405	-304.09	131.33	73.57	-175.65
0 right	200	-15.405	-304.09	131.33	73.57	-175.65

Final pre stress moment after pre-stresses losses is calculated and presented in Table-5f.

Table-5f. Final Pre-stress Moment after loss.

	Initial pre-stress Force in t	**Loss of force**	**Final pre-stress Force after loss in t**	**Initial pre-stress moment tm**	**Loss of Moment**	**Final Pre-stress moment after loss in tm**
	35	36	37	38	39	40
	∑8	31	35+36	20	34	38+39
0 left	2383.93	-304.09	2079.83	1438.2	-175.6	1262.6
0 right	2383.93	-304.09	2079.83	1438.2	-175.6	1262.6

Stress due to Pre-stressing after all losses of pre stress at top and bottom is given below

Table-5g. Stress due to Pre-stressing after losses at top and bottom.

	Area (cm^2)	**Zt x10^5 in** (cm^3)	**Zb x10^6 in** (cm^3)	**Direct stress after loss** (kg/cm^2)	**Ft bending after loss top in** (kg/cm^2)	**Fb bending after loss bottom in** (kg/cm^2)	**Pre-stressing stress after loss Top in** (kg/cm^2)	**Pre-stressing stress after loss bottom in** (kg/cm^2)
	41	42	43	44	45	46	47	48
	11	21	22	37/41	40/42	40/43	44+45	44+46
0 left	57866.8	55.00	-42.82	35.94	22.96	-29.49	58.90	6.46
0 right	57866.8	55.00	-42.82	35.94	22.96	-29.49	58.90	6.46

Stresses due to dead load and live load moment will give tension at the top face of the cantilever i.e. at 0L section. These values will be the same for section at just right of 0L, at 0L and at just left of 0L. Stresses at top and bottom due to dead load (D.L.) and live load is calculated below in Table-5h.

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Table-5h.

	All dead load moments in tm	All live load moments in tm	D.L. + L.L. moments in tm	Zt x10^5 in (cm^3)	Zb x10^6 in (cm^3)	DL and LL stress in Top in (kg/cm^2)	DL and LL stress in bottom in (kg/cm^2)
	49	50	51	52	53	54	55
			49+50	21	22	51/52	51/53
0 left	-2593.6	-999.1	-3592.7	55.00	-42.82	-65.3	83.90
0 right	-2593.6	-999.1	-3592.7	55.00	-42.82	-65.3	83.90

Stress due to pre-stressing after all losses plus stress due to D.L. and L.L. is summarized below and final stresses on top and bottom is calculated in the Table-5i.

Table-5i. Stress due to pre-stressing after all losses plus stress due to D.L. and L.L.

	Pre-stressing stress after loss Top in (kg/cm^2)	Pre-stressing stress after loss bottom in (kg/cm^2)	Stress due to DL and LL load at top (kg/cm^2)	Stress due to DL and LL at bottom (kg/cm^2)	Final stress top (kg/cm^2)	Final stress bottom (kg/cm^2)
	56	57	58	59	60	61
	47	48	54	55	56+58	57+59
0 left	58.9	6.5	-65.3	83.9	-6.4	90.4
0 right	58.9	6.5	-65.3	83.9	-6.4	90.4

Max Stress in flexural compression = 90.359 < 118.96 Kg/Cm^2 for M35
Max Stress in flexural tension = -6.424 >0 Kg/Cm^2

The probable causes of distress

It is the general observation that whenever any failure occurs in a structure in operational period the cause of distress is generally not single and there are many errors during the planning, design and execution stage that have cumulative effect leading to distress. The maximum hogging moment at the face of the cantilever at 0L near P1 due to Dead load is -2593.554 tm and due Live load is -999.1 tm. Stresses Produced by these moments at the top and bottom are -65.3 kg/cm^2 and 83.9 kg/cm^2 respectively. External Stresses induced by Pre-stressing force after considering all losses at top and bottom are 66.42 kg/cm^2 and 6.5 kg/cm^2 respectively. Final stress at the top is 1.102 kg/cm^2, which is positive hence, safe. Final stress at the bottom is 90.39 kg/cm^2, which is less than the allowable stress in flexure compression for M35 grade of concrete (118.96 kg/cm^2) therefore, the number of strands provided (232) is sufficient to counteract the final design moment. Detail of the pre-stressing cables provided is shown in table number 3.

At this section (at the face of the cantilever near pier P10) cable number VIII (4x8= 32 strands) has been curtailed without bothering about the section just left of it Figure-6 and Figures 8 and 9. Now considering the section just left of the above section i.e. 0L. Stresses Produced by dead load and live load moments at the top and bottom will nearly be equal to the same as at 0L i.e. -65.3 kg/cm^2 and 83.9 kg/cm^2 respectively. But now only 200 strands are available, i.e. there is a deficiency of 32 strands. External Stresses induced by Pre-stressing force after considering all losses at top and bottom will be reduced to 58.9 kg/cm^2 and 6.46 kg/cm^2 respectively. Final stress at top is -6.42 kg/cm^2, which is negative, hence unsafe as no tension is allowed in service condition clause 7.2.2 of IRC18 2000. Final stress at the bottom is 90.39 kg/cm^2, which is less than the allowable stress in flexure compression for M35 grade of concrete (118.96 kg/cm^{2}as per clause 7.2.1 of IRC18 2000). The moment due to DL and LL just left of this section will not reduce sharply and the number of strands required, will be the same, but there is a sudden deficiency of 32 strands Figures 8 and 9. Hence, there is a shortfall in the pre-stressing, and it is reflected by the structure as the crack is just left of the section.

CONCLUSIONS

From the above one can arrive at a definite conclusion regarding the cause of failure. While designing the PSC balance cantilever span, attention should specially be focused on the face of the cantilever as well as the section between 0L and 0.15L of supported span. Cable profile should be critically examined as hogging moment does not die completely in this zone. In design of present bridge stress check has been carried out at 0L , 0.1L, 0.2L … and so on, it should be on a closer interval or at every meter while designing the bigger span and near the zone of curtailment of strands. The detail calculation of stresses shows that the crack on the main member is due to faulty design and other distresses and damages are due to poor quality of construction. Such deflection of the cantilever can occur due to a shortfall in the pre-stressing. Similar deflections were observed in the Narmada River Bridge at Punasa dam, Meli Bridge in Sikkim, Zuwari Bridge in Goa and these are being rectified by external pre-stressing. If

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the deflection is not controlled it will go on increasing, the structure is likely to collapse and therefore this should not be ignored.

REFERENCES

[1] IRC: 18-2000. Design criteria for pre-stressed concrete Road bridges (post tensioned concrete). Standard specifications and code of practice for road bridges.