

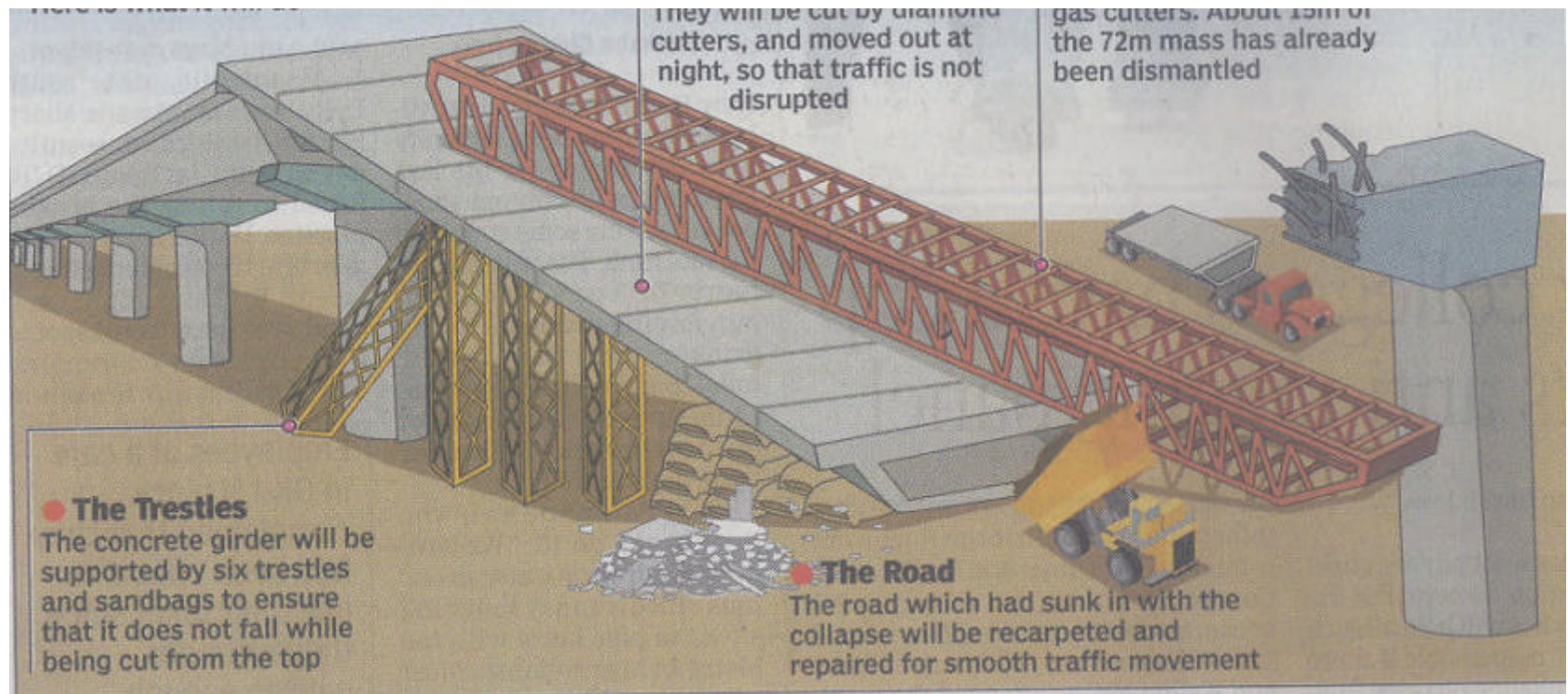
Failure at Delhi Metro

An Analysis

15th Jul' 2009

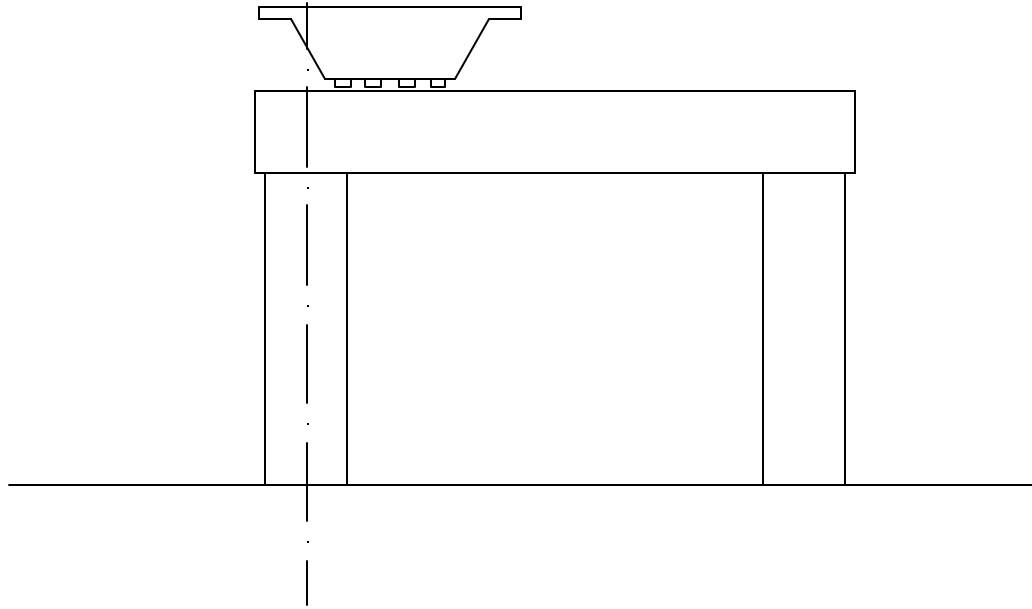
- H K Garg

- ❑ **PICS OF FAILURE**
- ❑ **BACK GROUND**
- ❑ **CHANGE IN DESIGN CONCEPT**
- ❑ **PART CONSTRUCTION AS PER OLD DESIGN**
- ❑ **OLD DESIGN CONCEPT**
- ❑ **CRACK DEVELOPMENT**
- ❑ **RECTIFICATION MEASURE**
- ❑ **CAUSE OF FAILURE**
- ❑ **THANK YOU**

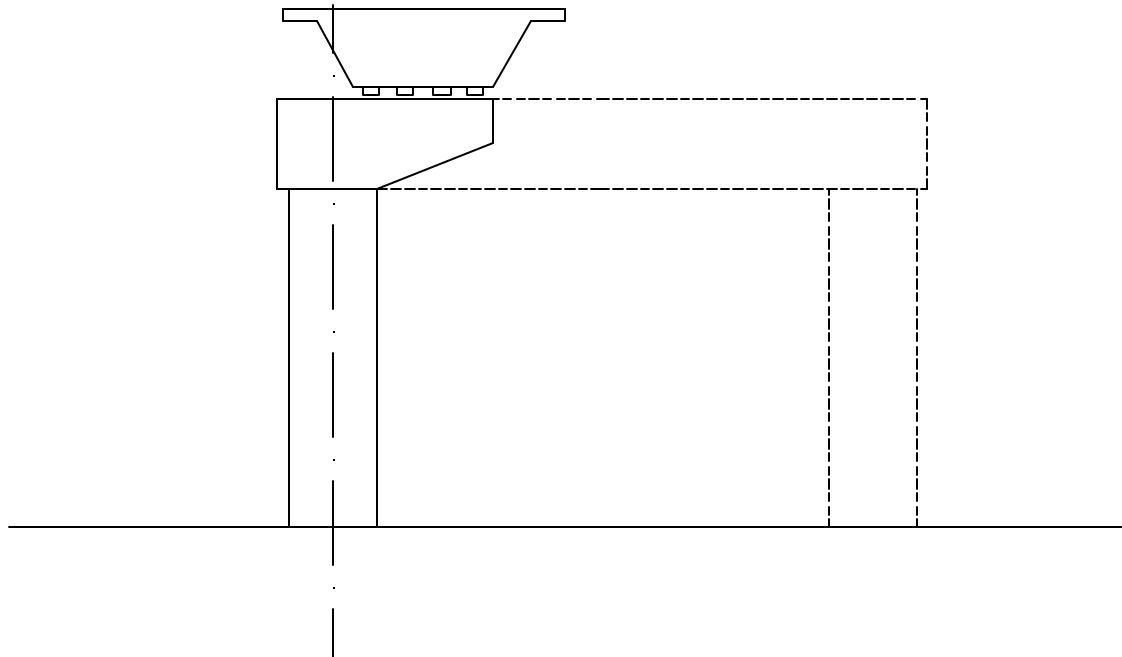






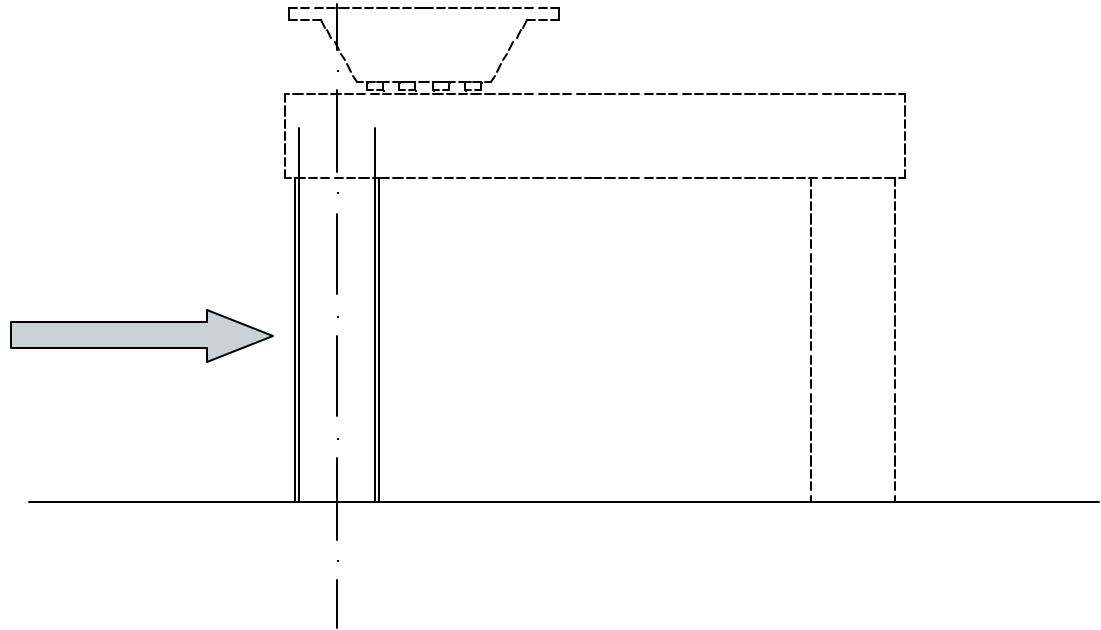


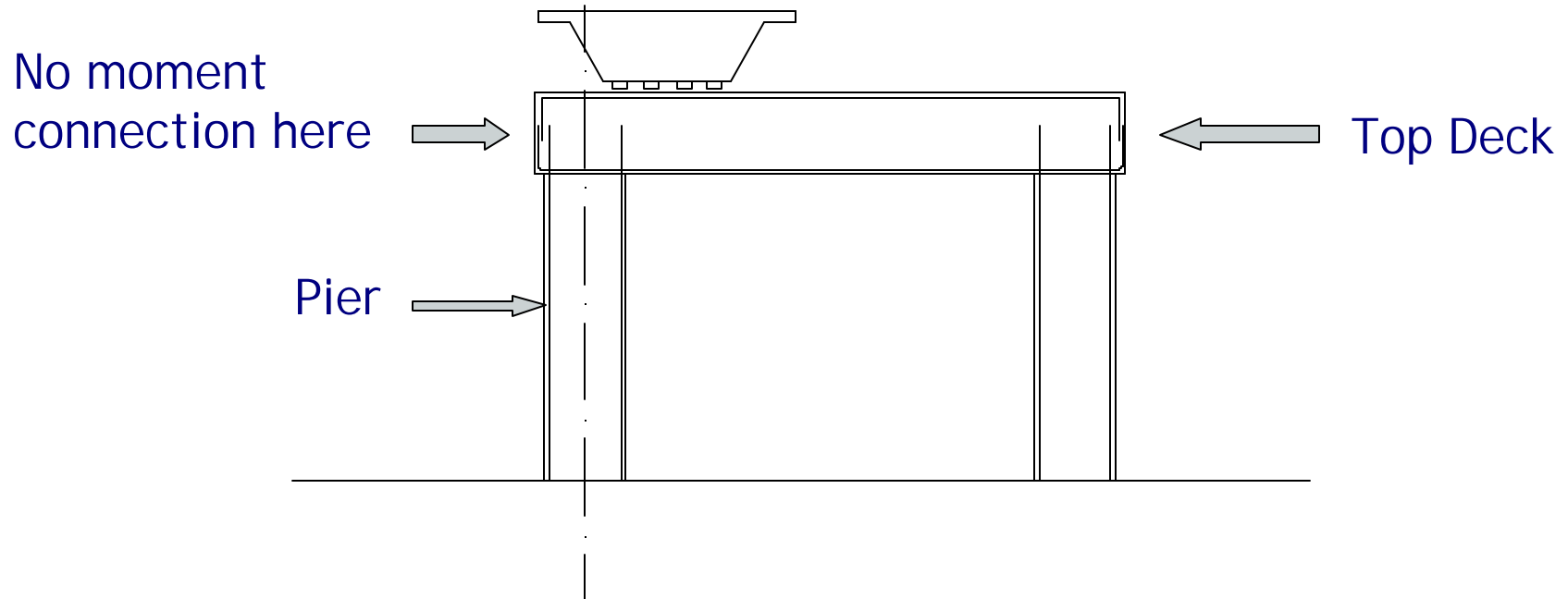
The rail track alignment takes a turn here. The top deck can not be placed at the centre of the pier. 4 nos piers (66-69) were initially proposed to be portals.



This being a congested area, the 2nd pier was coming pretty close to the adjoining shops. Due to resistance from the shopkeepers, these portals were converted into cantilevers supported on single pier.

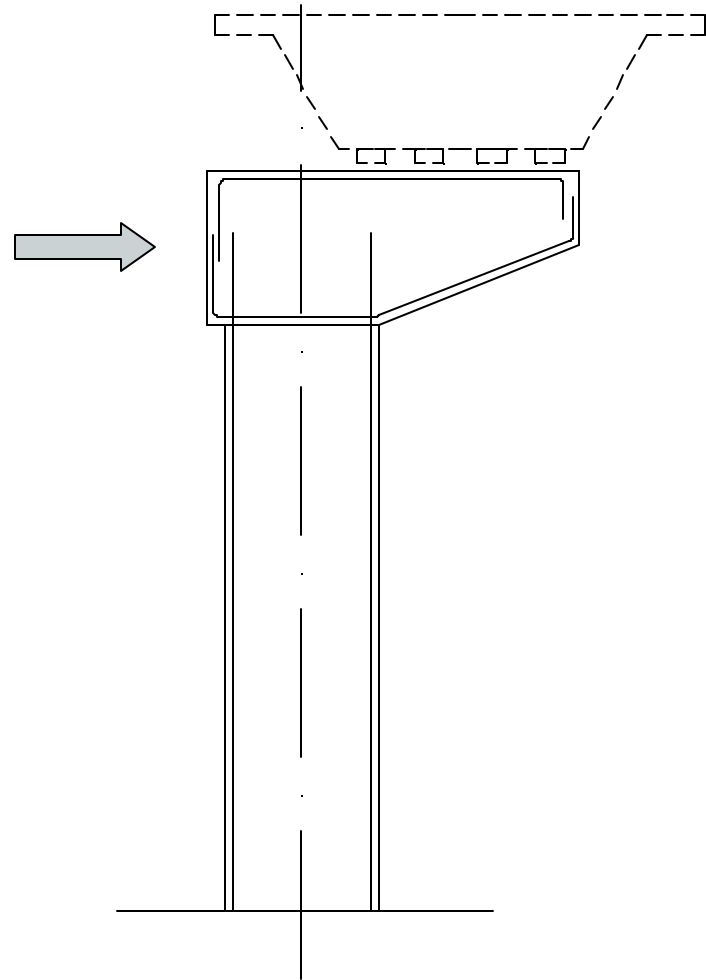
The pier already constructed with dowels as per old design.



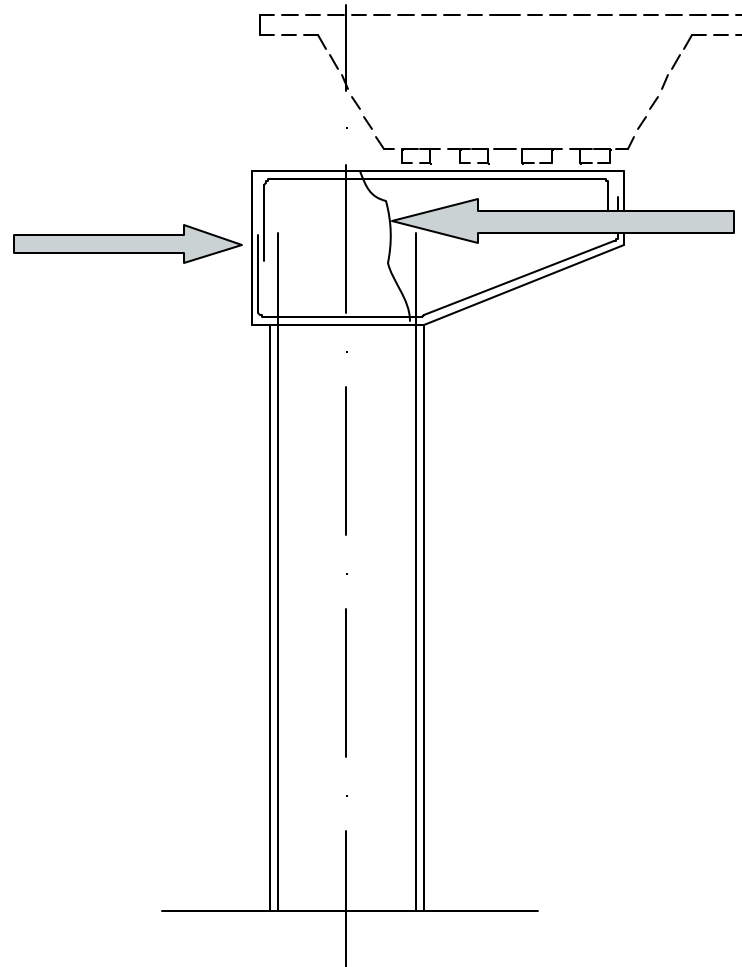


The top deck was probably designed as simply supported on piers

The portal is converted into
long cantilever approx 4.5 m

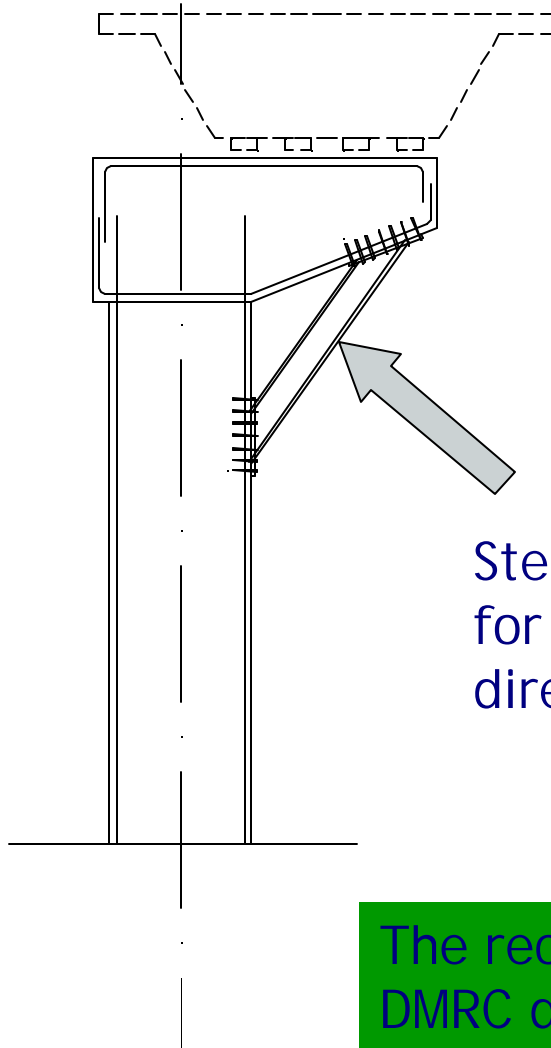


Probable Cause –
insufficient lap of
deck top tension
rebars with pier's
projected rebar.
The cantilevered
deck shows signs
of failure as
crack.



Top deck
develops crack
while erecting
segments of
previous stretch
i.e. between pier
66 – 67

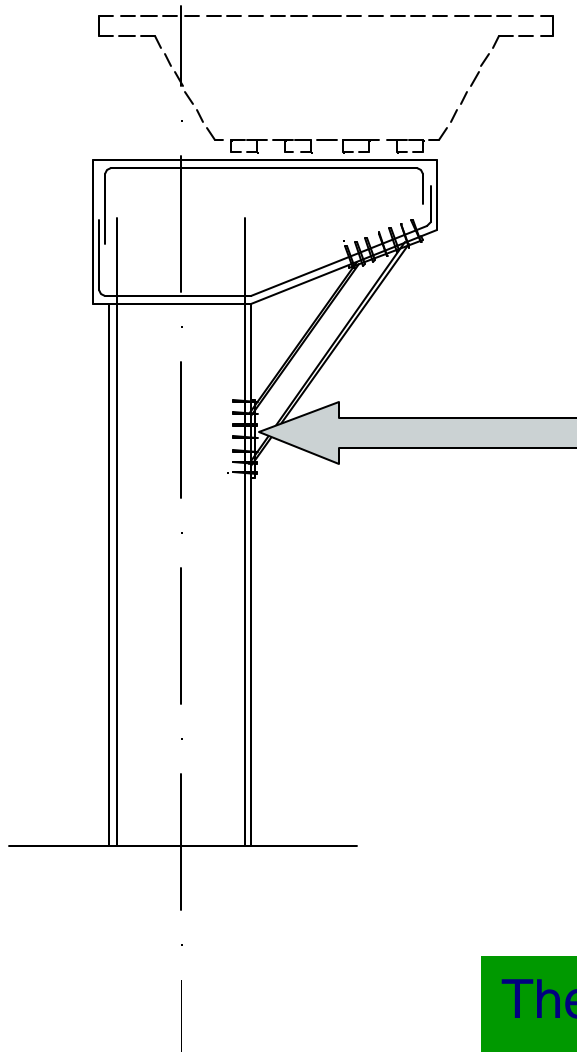
The work is stopped for almost 2 months for deciding rectification measure



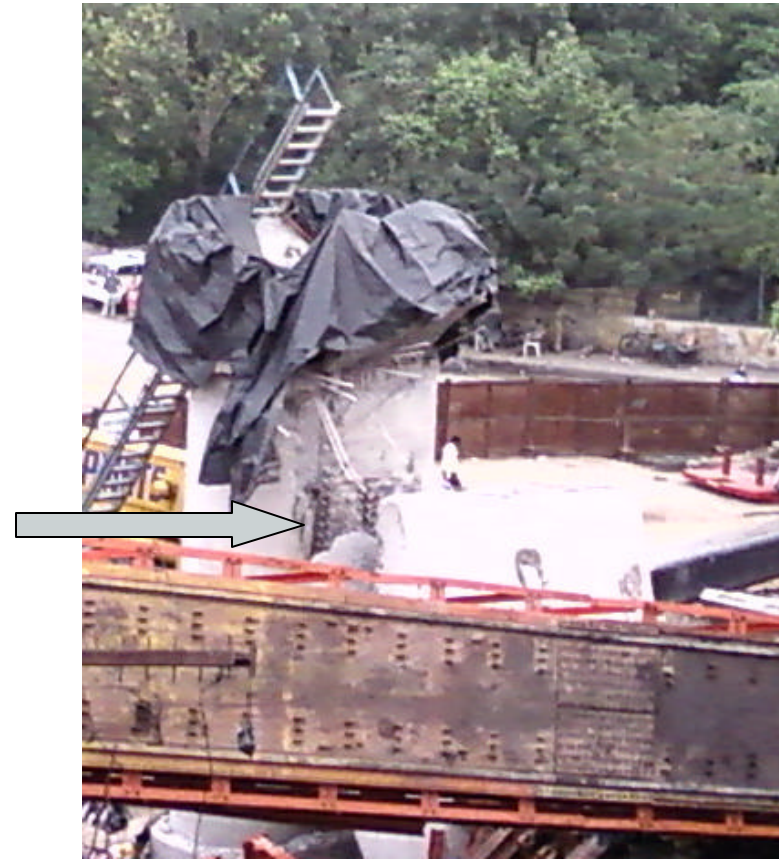
Steel knee bracket is provided
for transferring the load
directly to the column



The rectification measure was duly approved by
DMRC designers



Steel bracket's weld with end plate fails keeping the bracket plate and anchor fasteners intact.



The top deck again acts as cantilever and fails in moment due to In-sufficient lapping of bars



Thank You

FAILURE ANALYSIS OF MISHAP AT DMRC SITE ON 12TH JULY, 2009 – A REPORT

1. BACKGROUND

- A. On 12th July, 2009, while lifting segments of the superstructure, an accident happened in the Badarpur – Secretariat section near P-67. The pier cap of pier P-67 got collapsed causing subsequent collapse of the (i) Launching Girder (ii) Span between P-66 and P-67 which had got erected and pre-stressed, already (iii) Segments of the superstructure for the span between P-67 and P-68. The incident left 6 people dead and many injured.
- B. On 13th July, 2009, while clearing the site of all debris, 4 cranes were deployed by DMRC for taking out the entrapped launching girder. Three out of four cranes failed during this operation.
- C. The contractor involved in this case was M/S Gammon India who deployed a PRW contractor namely M/S Vijay Yadav for all these works.

2. SITE VISIT

A site visit was carried out to investigate the possible reasons of such failure (s).

A. Observation – 1

The pier cap of affected pier (P-67) has sheared from the connection point of the pier and pier cap. It is a cantilever pier cap.



It was informed by the contractor and DMRC representatives that the support system for viaduct was initially designed as portal pier till the casting of the pier was over. The shop owners put up

resistance against casting of the other leg of the portal and it was subsequently decided by DMRC that this would be changed to a cantilever pier, similar to P-68 which is still standing at site (shown below).



B. Observation - 2

It was noticed that the prop support of the cantilever has failed from its connection to the pier.



The prop support has sheared from here

C. Observation - 3

The top reinforcement of the cantilever beam does not have any development length into pier concrete. As learned from the sources, the top reinforcement of the cantilever beam had an "L" bend of 500 mm only.



Top reinforcement does not have development length

There is very nominal (or no trace) of shear reinforcement at the juncture.

D. Observation – 4

The launching girder has fallen below with the failure of pier cap. Also, the span between P-67 and P-68 has fallen inclined, supported by the ground at one end and pier cap (P-68) on the other.



E. Observation – 5

The boom of the crane, used for lifting the launching girder on 13 July, 2009, has failed in bending and shows clear sign of overloading.



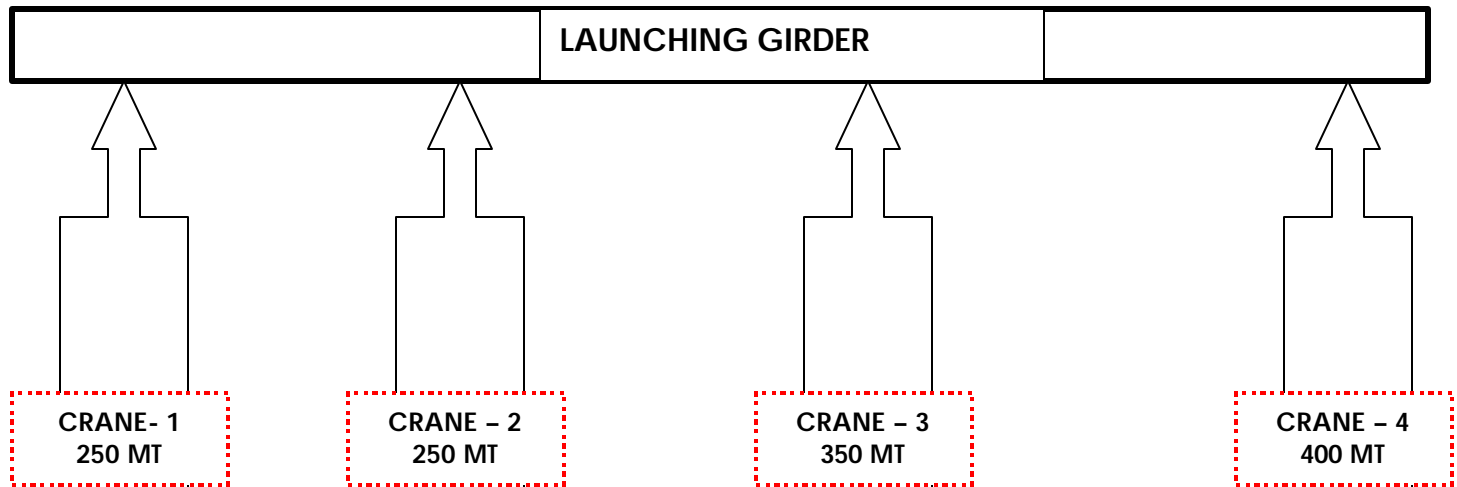
3. ANALYSIS

A. The Pier Cap Failure on 12 July, 2009

- i. The pier (P-67) was initially designed as a leg of a portal frame and subsequently changed to support cantilever pier cap.
- ii. The same method was followed for P-68 and P-66.
- iii. The alignment of track here is in curvature and gradually leaves the median of the road to align on one side of the road.
- iv. The longitudinal reinforcement of the pier was protruding by around 1500 mm beyond top of pier.
- v. The top reinforcement of pier cap was 36 mm in diameter and had a development length of 500 mm. only as an "L" from the top. There was insufficient bond length for the structure to behave like a cantilever beam.
- vi. During launching operation of the launching girder itself, this pier cap developed crack and work was stopped for couple of months. During this period, the cantilever pier cap was grouted in crack areas and further strengthened by introducing prop or jacketing as shown in observation - 1.
- vii. However, the behavior of the structure changed due to introduction of this jacket and the cantilever pier cap remained no more cantilever.
- viii. The segments of superstructure for the span between P-66 and P-67 was erected and launched and the prop beam / jacketing could sustain the load to that extend.
- ix. During the launching of superstructure segments between P-67 and P-68, only 6 segments could be lifted and the whole system collapsed when seventh segment was hooked for lifting.
- x. The sequence of failure is as follows:
 - a. The support of the prop / jacket got sheared from its connection due to inadequate section / welding.
 - b. The cantilever pier cap which was behaving as a simply supported beam due to introduction of prop / jacket started behaving like a cantilever beam suddenly after failure of the prop which it can not sustain (It was inadequately designed). SO, the so called "cantilever pier cap" collapsed.
 - c. The launching girder / span between P-67 & P-66 / the temporarily erected segments between P-67 and P-68, all got collapsed in one go.

B. The Crane Failure on 13 July, 2009

There were four cranes operating simultaneously as shown in the sketch



The launching girder was lifted by the cranes. However, it needed to be pushed little forward for unloading it on the ground. So, all the cranes were asked to stretch their booms by some length. During this operation, the 250 MT capacity crane on extreme left exceeded its capacity and the boom failed and broke down. Since, there was unequal loading on the 250 MT crane by its side, that also failed and broke down. The crane of 350 MT capacity didn't break but it toppled with its base. The 400 MT crane remained intact.

4. CONCLUSION

- It is concluded that the failure of pier cap occurred due to inadequate prop / jacket. This was coupled with failure of cantilever pier cap due to inadequate development length of top reinforcement of the cantilever pier cap.
- The failure of the crane was a case of operational inexperience for such synchronized crane operation. The crane -1 did not have the requisite capacity for the extended boom length and radius. Once crane - 1 failed, the crane - 2 was loaded almost half of the launching girder amounting to around 200 MT. For the extension of boom and radius, it did not have the requisite capacity so it failed, too. The crane -3 was loaded more than its capacity. However, in this case the crane got toppled instead of boom getting sheared. The crane -4 did not undergo the severe loading due to failure of other 3 cranes and most of the loads got grounded by that time.

5. LESSON LEARNT

- Structural designs should be proof checked by experienced structural engineer.
- Once failure observed, structure should be as far as practicable abandoned and new structure should be built up

- c. More emphasis should be given on detailing of reinforcement to cater for connections and behavior of the structural components.
- d. Any make-shift arrangement to save a failed structure should be avoided.
- e. Reinforcement detailing in corbels, deep beams, cantilever structures should be checked as per the provisions of more than one type of Standards (both IS & BS should be followed).
- f. Adequately experienced Engineer / Forman should be deployed for erection works.
- g. In case of synchronized crane operation, sufficiently designed "working of cranes" including checking by an experienced erection engineer should be documented in method statement and work should be taken up as per the method statement including fixing of location of hook of the crane, maximum boom extension, working radius etc.