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A Pragmatic Approach Towards Avoiding Uncertainties in Construction of Metro Rail

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***Abstract*— As a successful effort of providing efficient transportation facilities to the exponentially increasing urban population, Metro Rail Transit Systems have proved to be noteworthy. But such large projects demand a lot of research in safety, analysis and risk management to be established. In addition to the traditional safety precautions during construction, there needs to be a more sensible and realistic approach in the methodologies used during construction of Metro Rail. This paper presents two case studies which provide an insight into learning from past failures and challenges during construction in order to make future successes possible.**

***Index Terms*— Metro Rail, Uncertainties, Safety, Accidents**

I INTRODUCTION

Construction is the second largest economic activity in India after agriculture. It has accounted for around 40% of the development investment, during the past 50 years. The flourishing construction sector has thus given rise to rapid urbanization. As a result, the existing transport facilities are proving inadequate to fulfill the surging demands. This need for a sustainable mode of transport has given birth to the development of metro rail systems in some of the major cities in India.

But there is a darker side to this explosive growth and development. For all the big stakes involved, the construction sector has scant regard for the safety of those who work in its lowest rungs. Several repeated mishaps occurred during the construction of metro rail projects in India have created a cause of death for the workers at site. This paper focuses on two such case studies viz the first one where proper planning and supervision would have avoided a fatal accident, while the second one demonstrates how application of a preventive technical approach could avoid probable mishaps during construction of metro rail.

II LITERATURE REVIEW

Janet K. Yates [6] et al (2002) conducted a research on methods of investigating and documenting the various causes of failures in construction. They recommended certain incorporations in construction failure reporting efforts such as providing proper training for the personnel, prescribing a review process for formwork design and construction, provision of additional training by OSHA (Occupational Safety and Health Administration) & AEPIC (Architecture and Engineering Performance Information Center) in preventing failures, case studies on incorporating lessons from failure in undergraduate and graduate courses of construction, structural engineering and architecture. This research focused on how lessons can be learned from case studies of failures can obviate their recurrence, thus reducing some of the risks of injury and delay claims. Ramanathan [7] et al (2012) described how Metro rail has come up as a favorite mass transit rail system in emerging urban cities. Metro rail system is acceptable as a sustainable transport system which also facilitates sustainable development of the cities. The various steps discussed in this paper at various stages of development of metro rail system ensure a longer service life of these structures. Dilipkumar Patel [2]et al (2016) explored different types of sources where accidents statistics of construction industry may be available and then estimated the fatal accidents for NCT Delhi Region using linear interpolation and extrapolation. They derived an estimate at national level based on number of construction workers employed in states and their cement consumption. This estimate might draw the attention of various stakeholders of construction sector and motivate them to make safe work places and thus save the lives of workers.

III CASE STUDY

A. Delhi Metro Rail Project

The Delhi Metro Rail Corporation Limited (DMRC) is the body/authority in charge of the construction and operation of the metro rail system for Delhi (the capital city of India) and other National Capital Region (NCR) areas surrounding the city of Delhi. The project is a joint venture with equal equity participation from the Government of India (Ministry of Urban Development) and the Delhi Government. At present, Phase III of the Delhi Metro Rail Project is under construction.

Incident 1

It was during the construction of Phase II of Delhi Metro Rail Project, that on 12th July 2009, while lifting segments of the superstructure, an accident took place 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.

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Initially the support system for viaduct was designed as portal pier till the casting of the pier was over. The shop owners in the nearby area 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 as shown below.

The top reinforcement of the cantilever beam did 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.

There was insufficient bond length for the structure to behave like a cantilever beam.

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

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. However, the behavior of the structure changed due to introduction of this jacket and the cantilever pier cap remained no more cantilever. 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. 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.

Lessons Learnt

a. Structural designs should be proof checked by experienced structural engineer.
b. 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. Adequately experienced personnel should be deployed for erection works.
   Departments of construction companies should summarize basic safety rules, technical requirements, and other safety knowledge, and compile them as safety behavior standards. They can use the standards to train employees, and employees can gain safety knowledge and reduce unsafe behaviors.

Incident 2

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.

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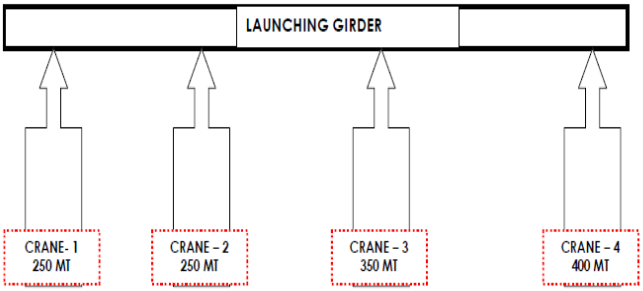
The boom of the crane, used for lifting the launching girder had failed in bending and showed a clear sign of overloading.

There were four cranes operating simultaneously as shown in the sketch



The launching girder was lifted by the cranes. 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 it's 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.

Lessons Learnt

a. Adequately experienced Engineer / Foreman should be deployed for erection works.

b. 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.

c. The use of different capacity cranes created an unbalanced condition resulting in their failure.

B. Kolkata Metro Rail Project

Kolkata Metro Rail Project work in the year 1987-1989 included the construction of an underpass located at northern end of Dumdum station. This tunnel had to pass under six suburban tracks at a skew angle, with cushion varying from 1-3 meters. The requirement was to drive two parallel tunnels for two tracks. For the 250 meters long, 5.1 meters dia. tunnel, a special Blade Shield Technique (*FIG 1 & 2)* was developed.

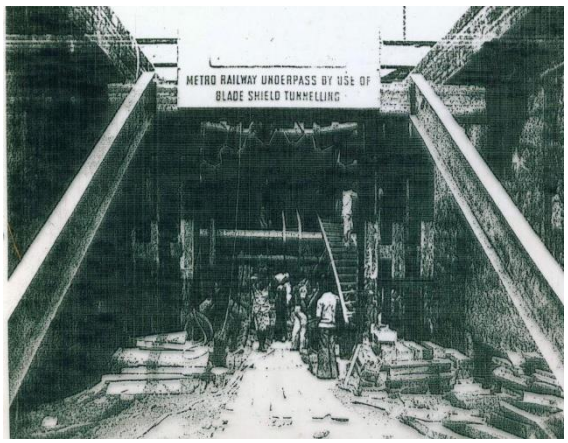


Fig 1

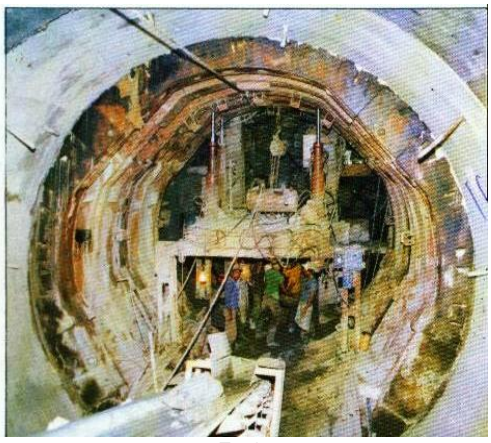


Fig 2

In this method segments (blades) were jacked individually to form a shield, due to which a very small jacking force was required to advance the shield in tricky ground conditions including strata consisting of cobbles and small boulders. In this process, ground cover requirements are minimum.

At the northern end of Dumdum station two parallel tunnels were required to be driven for two tracks. The contractors were using specially designed Blade Shield at the site. After driving 30 meters of the first tunnel the shield went in to a very loose pocket of earth (probably an old tank filled up during construction of embankment) , and the shield started tilting downwards. The shield tilted about 2 feet (600mm), and the tilt could not be arrested resulting in stoppage of work. The nosing down has to be first corrected by lifting the shield upwards, and secondly, any further chances of such nosing down, happening again have to be guarded and prevented. This naturally requires strengthening of the base under the tunnel. It was not possible to carry out this strengthening work from the surface, because of the heavy traffic on the suburban railway tracks. There was no other way than to carry out work from inside the tunnel.

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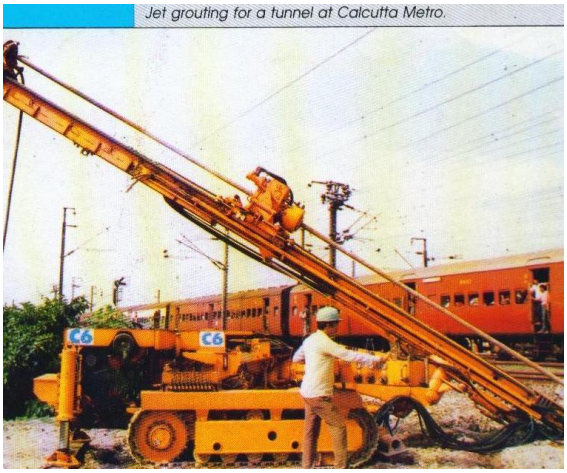
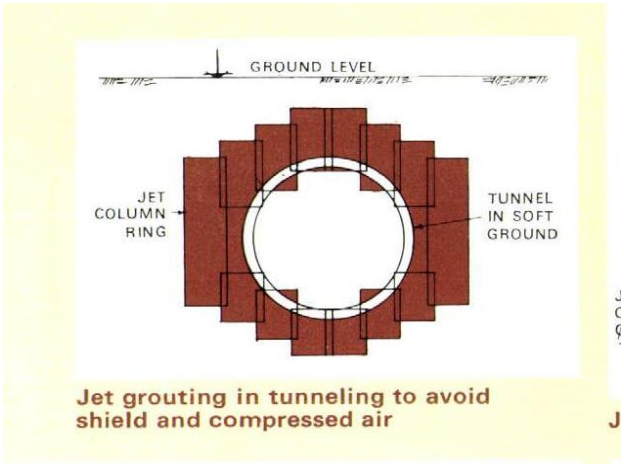
The engineers reviewed various methods and a most suitable method was considered wherein inclined jet grout columns are made by utilizing high pressure water jet technology to make the jet grout columns along with the tunneling.

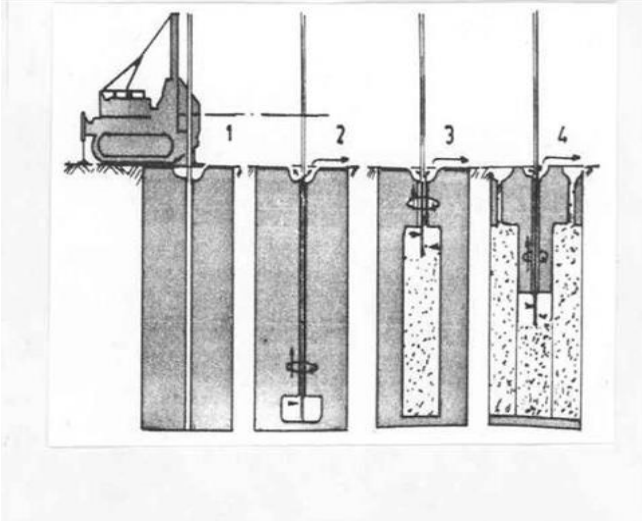
Jet Grouting Technique - It is an 'Injection Technique'. In which the soil mass is mixed in place with stabilizing mixture under a very high nozzle pressure (300kg. /cm2). Soils from gravel to clay can be treated by this method. This is called as 'Replacement-Displacement Grouting Technique. The energy of high speed water jet is used in disintegrating or cutting the soil and even rock. It has been observed the energy of water jet gets dissipated below ground water level; as such the same is surrounded by an air jet, which reduces the dissipation of the energy of the water jet under submergence condition. The soil is removed by the jetting action as explained above and it is replaced by the grout, which is injected at high pressure. The grout materials used are cement and water and with additive as required.


Jet grouting for a tunnel at Calcutta Metro.



Jet grouting in tunneling to avoid shield and compressed air

General Sequence and Method of "Jet grout column Construction" can be seen in the sketch given below



1. Complete drilling a hole as per required depth.

2. Jetting commences with "Monitor and grout pipes positioned at maximum depth and proceeds withdrawing at a steady rate . The size and shape of grout column (column geometry) as required is done by rotating rods while withdrawing at a controlled rate The pipes are provided one or more radial nozzles at its bottom, for jetting of the mix under very high pressure,

3. The upper high pressure water jet with air erodes column of soil while grout is simultaneously placed in the cavity by lower jet . The eroded soil air and grout escapes to the surface through the annular space between the bore and the grout pipes. It is followed by the grout forming the "Jet Grout Column". The strings of rods along with "Monitor" are raised as the grouted column gets formed.

4. Shift the rig and repeat the process to form more "Jet Grout Columns"

Jet Grouting treatment was carried out for a length of 250 meters of the Underpass tunnels in a total time of 24 months. In this initial 3 months were required in Site mobilization, finalizing the Grout mix designs (Oct.87, toDec.87), while in March, May and August 88, further 3 months were lost in Shield lifting, and making change in the jet Grout Technique from "Rodinjet-3 to Rodinjet-1system. Hence the work was completed in only 18 months.

V CONCLUSION

Metro Rail Project being a Mass Transit System is susceptible to many construction uncertainties. To learn and analyze from the previous mishaps and to think indifferent in challenging technical problems is the key to success. The first case study shows an accident due to negligence on site as well as inadequate proof checking of design and improper planning. Learning from past mistakes and rectifying them in the future should always be a priority. Also, with setting out well defined safety guidelines during design and execution of the activities, such large construction projects can safeguard the life of the workers.

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Whereas in the second case study, while carrying out Blade Shield Tunneling the soil stratum was stabilized by Jet Grouting Technique, to ensure travel of shield in correct level alignment. This solved the problem of Nose Diving into the soil. Such divergent thinking can always lead to success in many difficult situations. Hence such a pragmatic approach is necessary at times to help prevent uncertainties in construction of large projects like Metro Rail.

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