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Building collapse and ground subsidence in northern section of Calcutta Metro Construction

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ABSTRACT : The paper presents the case history of a building collapse in contract section 7 of Calcutta metro construction. A 5-storey building adjacent to a braced cut with R.C.C. diaphragm walls and struts collapsed after a 600 mm dia unfiltered water main gave way and water began to flow into the excavation under high pressure with consequent soil loss through openings in diaphragm walls. Extensive soil stabilization was done by cement / cement sand grouting before work could be resumed and the underground construction completed in the affected area.

1 INTRODUCTION

A major ground subsidence occured at 191, Chitta Ranjan Avenue, Calcutta, leading to the collapse of a 5-storey building, in section 7 of Calcutta Metro construction on July 1, 1994. A 14.8 m deep excavation by cut-and-cover method with R.C.C. diaphragm walls and struts was in progress.

The diaphragm walls had been built in 1988-89 and excavation was commenced in October 1992. On 01.07.94 around 5 p.m. one 600 mm dia unfiltered water pipe line running parallel to the Metro alignment collapsed and water began to flow out of the pipe under high pressure. A big subsidence was soon noticed in the area between the building and the diaphragm wall and the building began to tilt towards the N-E corner. Immediate action was taken to shut down the supply of unfiltered water through the pipe. Yet, flow of residual water continued for some hours and the building continued to tilt. Measures were taken to dump earth/sand bags inside the trench close to the diaphragm wall. The building was evacuated and movement of road vehicles on the western carriage way of C. R. Avenue was stopped. As the cavity in front of the building increased in size the building continued to tilt and finally, at 10.45 p.m. the building collapsed. Fortunately, there was no casualty or human injury and no damage was noticed in the diaphragm wall or supporting struts. Even the road decking in the vicinity of the subsided area remained free from distress. However, as a measure of precaution the adjacent buildings, 187, C. R. Avenue and 5, Parvati Ghosh Lane were evacuated.

This paper present an investigation of the cause of building collapse and means undertaken to complete the construction in the affected area.

2 SUBSOIL CONDITION AND CONSTRUCTION PROCEDURE

Fig.1 shows the Calcutta Metro alignment and the subsidence area in front of the collapsed building. The location of diaphragm walls and struts, major water mains and buildings in the vicinity of the affected area are shown in Fig.2.

Fig. 3 shows the subsoil condition in the collapse area as determined from detailed soil investigation prior to Metro construction. The subsoil consists of typical Normal Calcutta deposit with successive layers of silty clay / clayey silt and sand. The soil strata are particularly weak in the top 12 m as evidenced by low shear strength (C_u = 20 kN/m^2) . Thereafter, subsoil characteristics improve. The ground water table is high during rainy season.

Cut-and-cover construction with R. C. C. diaphragm walls and struts had been adopted for most of the Metro construction in Calcutta. Design of the braced cut had been made from considerations of stability, bottom heave, clay bursting, ground movement etc. taking into account the safety of adjoining structures and facilities.

Fig. 4 shows the excavation profile for Metro construction in the subsidence area. 600 mm diaphragm walls were taken 4-5 M below the final cut depth i.e. into the dense silty sand stratum. The walls were propped against each other by 4 Nos. steel struts. While the depth of diaphragm wall ensured stability against bottom heave and clay bursting the struts and diaphragm wall were designed to resist the lateral earth pressure during excavation. That the design had been adequate from stability considerations is borne by the fact that the diaphragm wall and struts had remained stable even after the collapse. Also, more than 13 KM of Metro construction had been done without any failure of the support system.

3 UNDERGROUND PIPELINES

There are many underground pipelines / utilities along / across the Metro alignment. Some run parallel to the diaphragm wall, some across it. These pipelines were often supported by structural steel work on the diaphragm wall or on the earth immediately outside the diaphragm wall. Water leakages from old pipelines were not uncommon. Besides, the joints of these pipelines sometimes showed distress with ground movement and water started to leak through the joints. This water, along with subsoil water, found its way into the trench through weaknesses in the soil and openings in the diaphragm wall and often brought fine soil with it. Such soil loss would be detrimental to the safety of nearby structures because the resulting ground subsidence would cause undesirable settlement in the foundations.

4 NATURE OF SUBSIDENCE AND BUILDING COLLAPSE

The subsidence area was part of contract section 7 of Metro construction just South of Girish Park Station. Metro work was going on in the 5 KM stretch from Esplanade to Shyambazar since 1984. Diaphragm walls in the affected area were done in 1988-89 . The work of underground excavation was mostly over except for two small stretches of 65 M (near the collapsed zone) and 30 M (near M. G. Road station) where the raft construction was still to be done, Fig. 3.

At the time of subsidence the excavation had been done to 12 m depth with three struts. Work had been going on at this section for some months. Excavation was in progress at the 4th strut level. Subsidence of earth took place a number of times during the construction. On 15th June, 1994, a portion of earth subsided on the eastern side of the road opposite the collapsed building near the petrol pump.

Close inspection of the Metro trench showed visible gaps and openings in the diaphragm wall at the junction of adjacent panels near the collapsed area. Diaphragm walls were built in 3 m panels. In the whole of Metro construction by the cut-and-cover method (13.4 KM) about 8000 such panels had been built. Gaps in a few adjacent panels would not be unlikely in such construction. Attempts were made to close these gaps near the affected area by welding lagging plates to diaphragm wall reinforcements. Even then some cavities and voids could be detected behind the lagging plates. Water was coming through the gap in diaphragm wall with some force and sand bags were dumped on the floor of the excavation by

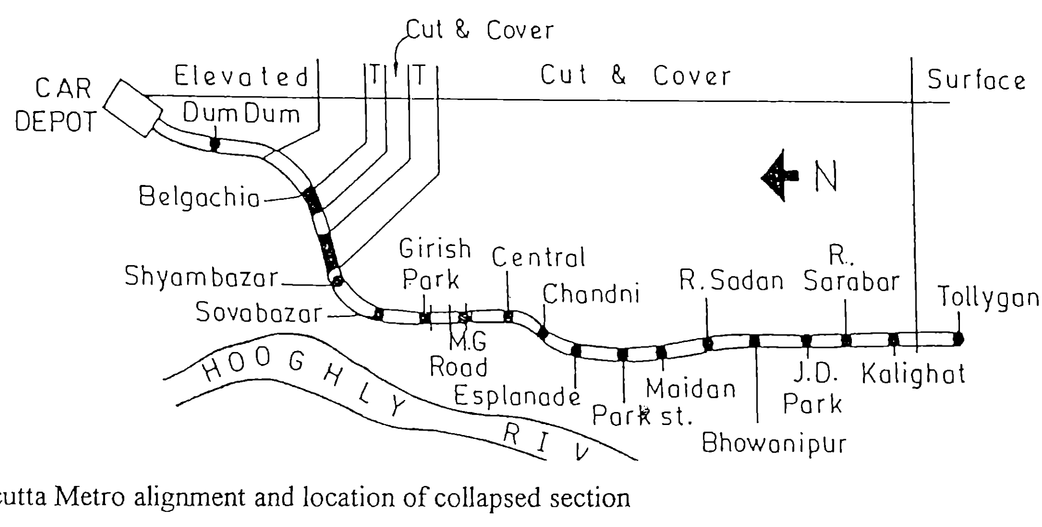

Fig. 1 Calcutta Metro alignment and location of collapsed section

the side of the diaphragm wall when the accident occurred.

A zone of subsidence in the collapsed building area measuring about 20 m x 10 m x 2 m deep was noticed between the diaphragm wall and the collapsed building after the removal of debris. This means that a volume of earth measuring 400 cum had subsided in the collapsed zone. This loss of soil did not take place in a single day. There was no evidence of upheaval of soil at the bottom of cut, nor did the diaphragm wall or struts show any major movement. The diaphragm walls appeared to stand well vertically and the struts also maintained their lateral position quite well. It was, however, gathered that there was persistent flow of water and soil loss through the gaps in diaphragm walls over a period of time. The gaps appeared to widen in deeper locations and lagging plates had been provided to close these gaps. But, the process of fixing lagging plates did not necessarily give a fool-proof system of preventing soil loss because the plates could not be fixed to the wall till the excavation had already progressed to that depth.

All these factors led to continued loss of earth through the diaphragm wall as could be evidenced from the deposition of soil at the bottom of the cut. Grouting was done in adjacent areas on either side of the collapsed zone to close the gaps in the diaphragm wall and to stabilize the soil for minimising the loss of earth from the side of excavation. Cement grouting was reportedly done in November, 1993. This was followed by polygrouting. Subsequently, cement grouting had been commenced near the collapsed zone. The latter was in progress when the incidence of collapse took place. Considerable soil loss appears to have occurred even before the stabilization measures could have any major impact.

Such soil loss into the excavation would have led to perceptible subsidence on the ground surface. However, the existence of hard road / pavement crust did not make void formation immediately apparent from outside. Voids created in the soil could have been retained by arching action. With progressive soil loss the earth supporting the pipelines finally caved in thereby causing the joints of the 600 mm pipeline to burst open. Water began to flow under high pressure causing rapid soil erosion close to the building. Normally, water from an underground pipe burst finds its way to the road surface. But, in the present case, possibly due to the prior formation of voids in the underground, the water from the collapsed pipeline forced its way down under high pressure leading to heavy soil erosion close to the building. This probably weakened the foundation and led to rapid tilting of the building. Although immediate action was taken to shut down the water from the pumping station residual water in the pipe continued to flow at high pressure for 5-6 hours. In the absence of isolating valves this flow of water could not be controlled earlier. By the time the rushing water was stopped sufficient tilting had occurred in the building to take it beyond the limits of stability. Continuous tilting caused further instability and the building finally collapsed when the deformation became excessive. (Fig. 5)

5 IMMEDIATE COURSE OF ACTION

In order to carry out further construction near the affected area the following actions were suggested :

(a) The subsoil in the area had possibly weakened by water flow. Soil stabilization would be required to strengthen the soil in the affected area so that further deformation was restricted.

(b) There was still some water coming into the excavation through the gaps in diaphragm walls. This was a source of potential danger as the water continued to wash away the fine soils and cause further ground subsidence. The most immediate task, therefore, was to stabilize the soil outside the diaphragm wall and to reduce the flow of water into the cut. This would be done by grouting on both sides of the cut near the collapsed zone. Cement or cement-sand grouting would be done to close the voids within the soil and strengthen any zone of weakness that still existed in the soil. The grouting would be done between the diaphragm wall and the building lines from outside the wall or by drilling holes from inside the diaphragm wall down to a depth of about 20 m below ground level. During grouting cement / cement-sand would to be plumped into the soil and the grout would spread into the soil through the void space and finally set in the soil to give it greater strength. Difficulties would occur in grouting under flowing water condition because of the chances of the cement being washed out. In such cases quick-setting additives would be added to the grout. Grouting would be continued at each place till refusal to accept cement and sufficient pressure was built up to indicate closure of voids / cavities.

(c) Adequate precautions were to be taken in further construction to ensure that ground subsidence was restricted and the buildings in the vicinity of the affected area were not further distressed.

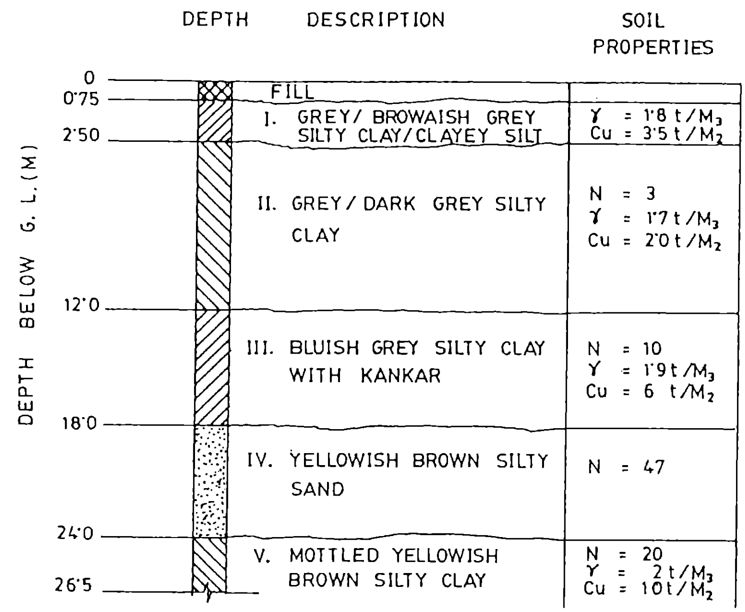

Fig. 2 Soil profile

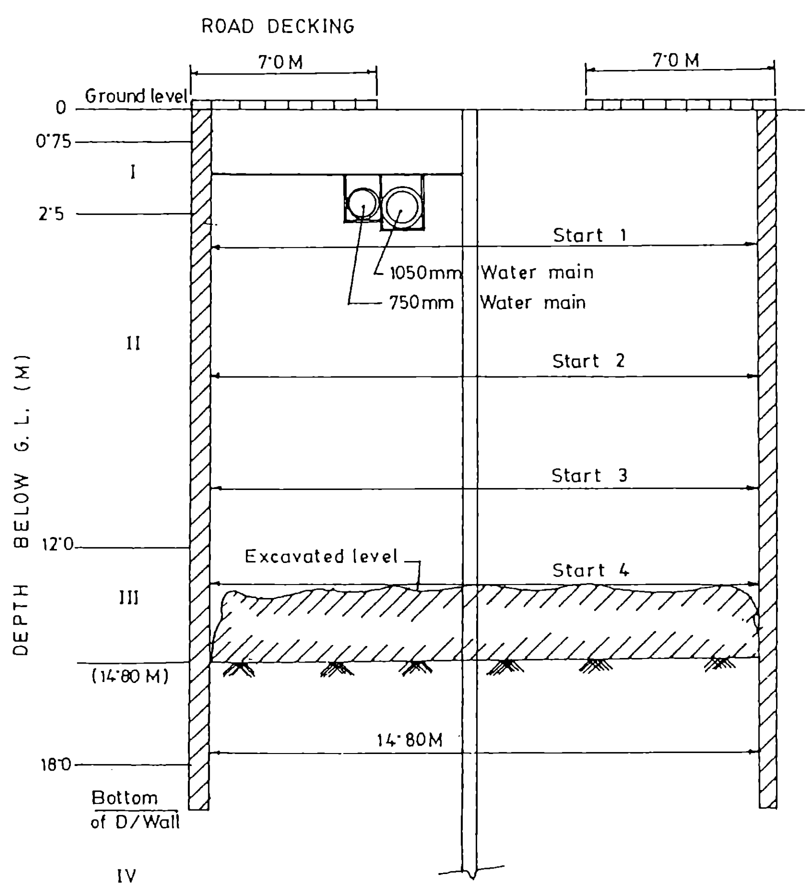

Fig. 3 Excavation profile near collapsed section

(d) Time is the essence of underground construction. Faster the construction better it is for the safety of the excavation and safety of surrounding structures. Undue delay in construction and stoppages of work increase long-term and creep movements in the soil.

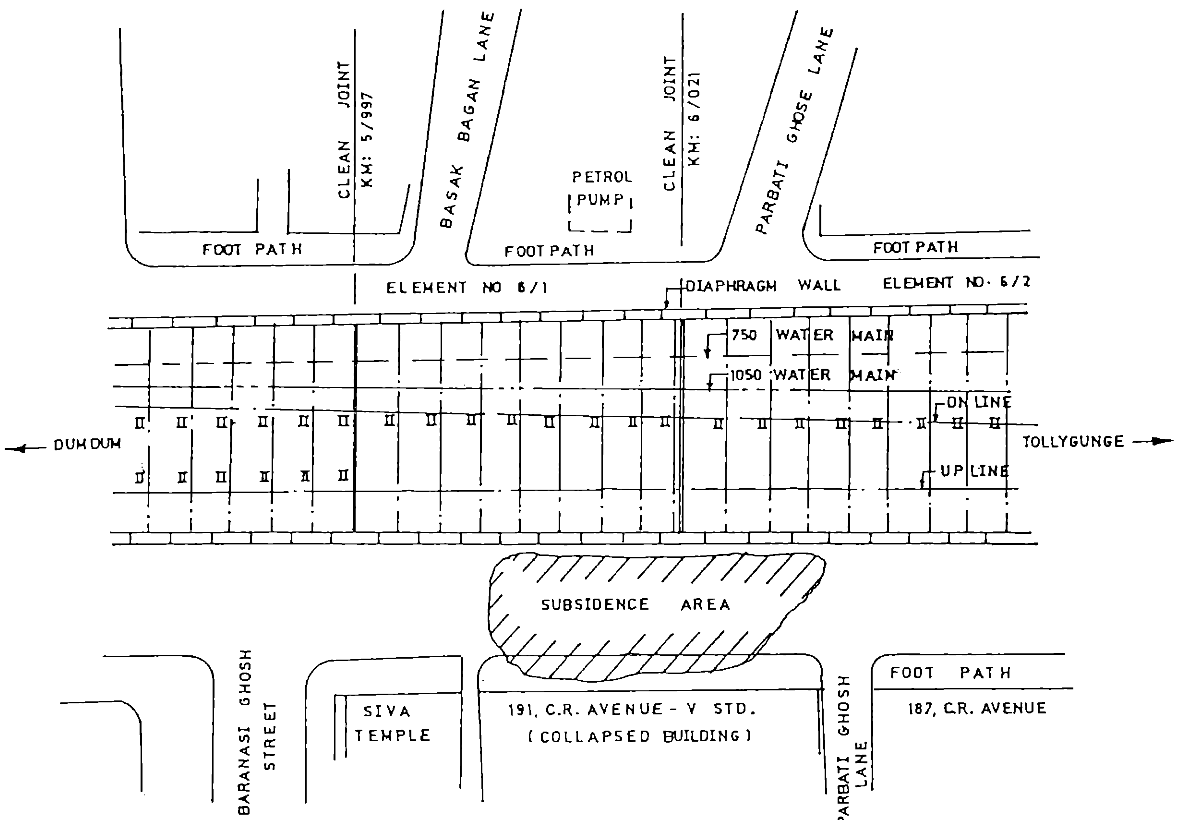

Fig. 4 Subsidence area in front of collapsed building

6 PRECAUTIONS FOR FUTURE WORK

The following courses of action were recommended as immediate measure :

(a) Work would continue in all stretches except the 65 m stretch in front of the collapsed building. All work pertaining to construction of raft, side wall, roof and back filling would be continued in these stretches to complete the construction fast.

(b) Grouting on both sides of the alignment near the collapsed zone should be continued till the soil stabilization work in the affected area was done. Till the stabilization work was substantially over, excavation and underground construction would not be resumed in the 65 m affected stretch.

(c) Sand bags that had been dumped at the bottom of the cut to provide counter weight and to prevent soil loss through diaphragm wall openings should be retained till the soil stabilization by grouting was done.

(d) After the demolition of the collapsed building was over, grouting should be extended to this area to stabilize the soil in the affected zone.

(e) The 450 mm dia water main on the eastern side of the excavation should be provided with valves at both ends of the affected stretch to quickly control any leakage of water in future.

(f) Premises No.187, C. R. Avenue and 5, Parabati Ghosh Lane, just next to the collapsed building should remain evacuated till the underground construction in the affected area was complete.

7 COMPLETION OF WORK

While the work in remaining stretches of Metro construction was completed without restriction, the work in the 65 m stretch near the zone of subsidence was undertaken only after soil stabilization by grouting was essentially over. The construction here was then resumed with the following precautions :-

(a) The sand bags were removed locally and excavation made in local trenches to place the 4th struts at the desired location.

(b) The full stretch of 65 m was not excavated at a time. The stretch was subdivided into four segments of 16 m each: The excavation and strutting in each segment was immediately

Fig. 5 View of Building after collapse

followed by the casting of the base raft without any loss of time.

(c) After the raft construction in the 65 m stretch the side walls were cast followed by the roof in the proper sequence and without loss of time.

(d) The box construction was be closely followed by back filling to restore the road surface.

The Metro construction in the affected area was completed in 1996 when the entire Metro was put into operation.

8 CONCLUSION

The building collapse in construct section 7 of Calcutta metro construction was caused by seepage of water into the excavation and consequent soil loss through the opening in diaphragm wall. Leakage in a 600 mm water main caused continuous flow of water into the excavation. Further construction in the area was done after extensive soil stabilization by cement / cement - sand grouting.