Rehabilitation of Low rise RCC Structure along 9m High Retaining wall

A. Nakhawa
Non Destructive Testing and Rehabilitation Experts, Maharashtra, India

V.B. Deshmukh
V.J.T.I. Matunga, Mumbai, Maharashtra, India

ABSTRACT

Mumbai is the financial, commercial and entertainment capital of India, facing bigger challenges in accommodating its over growing population day by day. The Mumbai City has population of 18.4 million over its 634 km² area, ie. Almost 350 ft²/person. This enormous rise in population density has restricted the development to expand vertically. This also, results in growth of major slums, which is almost 62% of the population dwelling in slums. Subsequently, the authorities is in need of a large scaled Slum Sanitation Program, which utilize the scarcely available land for construction of Community Toilet Blocks with involvement of NGO's and social experts like Tata Institute of Social Sciences. In this paper an attempt has been made to rehabilitate a G+2 public Toilet Block constructed in very densely populated slum along the hill side of Eastern Mumbai Suburb. The structure is recently constructed on the top of 9 m high retaining wall which has faced an incident of failure of old rubble retaining wall, during course of heavy rains at a rate 100mm in an hour. It caused the soil below the foundation to slip off partially. It was indeed a challenging job to retrofit and stabilize the Structure with best possible technology in the critical site as well as climatic conditions. The short-term as well as long term solution was recommended with the limitation of time and the availability of space. The paper presents, the approach to achieve, durable, sustainable - Structural and Geotechnical Solutions, for Rehabilitating the said (G+2) Structure and the 9m high retaining wall.

Key words: Rehabilitation, retaining wall, slum

1.0 INTRODUCTION

We live in an urban century, where more than 50% of the global population lives in urban areas. The United Nations estimates that by 2030, five billion of the world's population of eight billion will be urban.

In continuation to this rapid urbanization in developing countries has been characterized by an accompanying proliferation of slum areas. According to 2011 census, 62% of its urban population lives in slums.

Slums constitute a large part of today's urban reality and will likely persist as a significant feature in our urban future for decades to come. By 2030, projections indicate that two billion of the Sanitation poses the greatest challenges in the city's slum areas.

Slum populations have been forced to depend on public toilets to meet their sanitation needs. In a few locations, mainly large sites and services settlements, a sewerage network has been laid. In a limited number of cases, individual household latrines have been connected to septic tanks or are discharged into open drains. Overall, the city has not been able to cope with the existing sanitation needs of the slum communities, posing serious public health and environmental risks for the entire city's population.

The study conducted by ORF on the public toilets, reveals that many girls are forced to leave for school early so that they can use the toilets there. They resort to community toilets only when all else fails. Almost every girl recounted experiences of harassment they face while using community toilets, which usually has dysfunctional doors.

According to BMC's recent survey, 58% toilets in Mumbai's slums do not have electricity and 78% lack sufficient water supply. ORF Mumbai's study highlights that the infrastructure of the community toilets is poor. Badly constructed and maintained loose lead to sexual harassment of women in slums. There are very few toilet seats vis-a-vis the number of residents that forces women to defecate in the open, inviting trouble and loss of dignity. Many of these toilets do not have functional doors, latches and ventilators. The toilets do not have provision of dustbins and carrying a used sanitary napkin to the nearest dustbin invites comments which leave women with no option but to throw the pads inside the toilet. As a result, sanitary napkins lay strewn all over women's toilets and also stuffed in the ventilators making the toilets dingy, stuffy and smelly

In Mumbai, majority of the slums are dependent on public toilets. An estimated one person in 20 (or about 420,000 in total) is compelled to defecate in open areas; this represents about six percent of Mumbai's slum area population. About 17 percent have access to individual household latrines while nearly 72 percent depend on public toilets and five percent use a mix of arrangements. Insecurity of tenure, lack of space, and affordability constraints rule out use of conventional water-borne sewer based solutions.

Access to safe drinking water and basic sanitation can have a strong positive effect on human health (Raza et al. 1998; Fotso et al. 2007, Marobhe 2008).

A recent cost-benefit analysis by WHO (2007) showed that achieving the global Millennium Development Goal 7 for water and sanitation would bring substantial economic gains from both health and other benefits.

The financial capital of India needs large quantity of sanitation accommodated in small and hilly terrain areas. The supervising authorities are in need of a large scaled Slum Sanitation Program, which utilize the scarcely available land for construction of Community Toilet Blocks with involvement of NGO's and social experts like Tata Institute of Social Sciences. In this paper an attempt has been made to rehabilitate a ground with two storied public Toilet Block constructed in very densely populated slum along the hill side of Eastern Mumbai Suburb. The structure is recently constructed (Fig. 1) on the top of 9 m high retaining wall which has faced the incident of failure of an old rubble retaining wall, during course of heavy rains at a rate 100mm in an hour. It has caused the migration of soil below the foundation to slip off partially (Fig. 2). It was indeed a challenging job to retrofit and stabilize the structure with best possible technology in the critical site as well as climatic conditions. The short-term as well as long term solutions were recommended within the limitation of time and the availability of space. The paper presents, the approach to achieve, a durable, sustainable structural and geotechnical solutions for rehabilitating of the said community toilet block structure supported on 9m high retaining wall. The entire rehabilitation program was completed successfully into two major parts; restoration of foundation and health assessment of community toilet block structure with confirmatory testing.

Fig. 1 . View of Toilet Block Structure in Slum

The ground plus two storied R.C.C. community toilet block structure is supported on partial raft and remaining on the open foundations. The underground water tank and septic tanks are constructed within the raft foundation as shown in Fig. 2.

Fig.2. Partial Collapse of Old Retaining wall

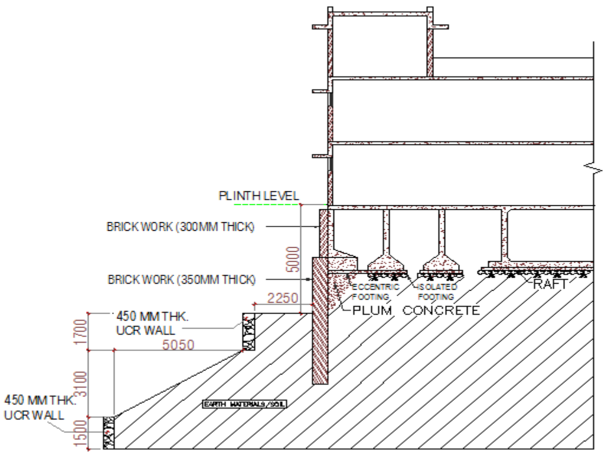

Fig.3. Cross sectional view through the wall and the building structure

Mumbai city experiences a heavy rainfall with high humidity round the year, moderate winters and hot summer which caused the structures more susceptible for faster deterioration and corrosion induced distress. Further, geographically, Mumbai has long sea-shore which has marine clay deposits in near shore. The hilly terrains slopes are deposited on compact laterite weathered rock overlain by silty-clay soil deposit consists of boulders. Subsequently they become unstable due to migration of fines due to heavy rain intensity. The present site condition site has suffered from similar adverse condition.

The rehabilitation work was carried out with the construction of Brick Wall and mass concrete filling below the partially open foundations of community toilet block structure. Subsequently pockets behind the retaining wall were filled up with grouting with rich cement slurry into the soil. Structural Health monitoring was carried out with visual inspection and Non-destructive tests as per Indian standards (IS13311 Part 1 and 2) such as ultrasonic pulse velocity and rebound hammer tests to assess the integrity concrete for the toilet block structure. ASTM codes are followed to ascertain the probability of corrosion and carbonation. In addition In-situ-Test progressive load test was also conducted at design load.

2.0 FIELD OBSERVATION AND ASSESMENT

The new Toilet Block structure was constructed as per conditions of government's sanitation program, as demolition and reconstruction site and that the designs for the said site were carried out as per the existing site plinth area and boundaries. The toilet block was reconstructed as per government sanitation program which occupied the same footprint of old building. The structure was supported on raft foundation partly where the underground water and septic tanks (Fig. 3). The outer portion of the structure was supported on eccentric footings.
The newly constructed ground plus two storied RCC community toilet block structure is a reinforced concrete Framed G + 2 building constructed with partial raft and open foundations. The raft foundation laid in the areas where the underground water tank and septic tanks are provided (Fig. 4) shows the schematic plan of the different foundations types laid over the plot area.

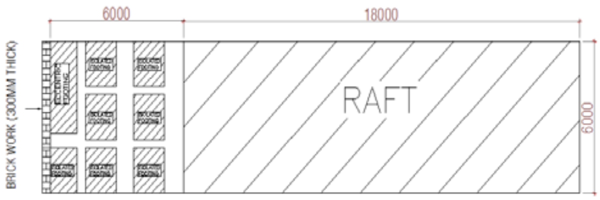

Fig.4. Schematic plan of the different foundations types laid over the plot area

The size of structure measures 24 x 6 m with the height being 9.2 m above ground level. The foundations are placed at 3 m below the average ground level. The RCC frame is raised above the foundation level with columns are spaced at distance of 2.1 m and 3 m c/c along the longer shorter span respectively.

The construction work was completed in mid of 2017 and was about to be handed over to the community for use. The old toilet structure was constructed over the rubble retaining wall. The new ground plus two storied structure replaced the old structure resting on the same rubble masonry retaining wall. The old rubble retaining wall was known to be constructed a couple of more decades ago and their existed a old structure which was demolished prior to construction of the new one as per the new sanitation program based on the demand of the community.

The foundations were designed with low bearing capacity of 10 T/m^2 at 3 m below ground level. The eccentric foundations were placed at 0.15 to 0.6 m away from the inner face of retaining wall. The 9 m high rubble masonry retaining wall was constructed for supporting the corner footing of the structure. The retaining wall was constructed on filled-up soil deposit.

In the last year monsoon (rainy season), due to high rainfall intensity duration of 100 mm/hr, the East Side of the retaining wall was partially collapsed. The high intensity of rainfall caused the rise of pore pressure, which subsequently increased the earth pressure. The high earth pressure swayed away the soil deposit beneath the foundation of retaining wall over the length of 10 m at two different locations as shown in Figs. 5 and 6. The retaining wall was in equilibrium condition as no crack was seen in the outer surface of the wall as well in the above structure.

Fig.5. Soil below the eccentric Footing is seen to be partially slipped off

Fig. 6. Soil below the eccentric Footing is seen to be partially slipped off

The entire rehabilitation work was divided into two stages.

I. Field Assessment and Rehabilitation of the Foundations and
II. Continuous Health monitoring of the structure by conducting NDT and load test on the structure.

2.1 Rehabilitation of Foundations

The immediate rehabilitation of failure was to seal the cavity beneath the foundation. The failure zone beneath the foundation was rectified by injecting low pressure cement grout followed by the false brick work of 450mm thick. The brick wall was raised gradually in stages of 0.6 m vertically from the level where it was disrupted. The gap of 0.6 x 0.6 m along the length between stabilized soil and brick wall was filled up by M25 grade concrete. Weep holes using perforated pipes of 0.65 m diameter were made aligned staggered at spacing of 0.9 m c/c. The brick wall of 450 -600 mm thick was plastered externally with 25 mm thick in 1:3 mix rich cement mortar. The rehabilitation work was observed at regular time interval for 45 days and no further distress was observed.

The slipped soil was stabilized by cement grouting and plastering the same (Fig. 7) – this was done immediately after a lapse of 4-6 hours from the partial collapse and was followed by a false brick work 450 mm thick, as immediate support mechanism, which was raised gradually from the level where the wall was disrupted, in stages of 600mm vertically. Grouting was carried out using rich cement slurry at low pressure. The gap between the stabilized Soil and the brick work was filled and casted with M25 concrete in stages of 600mm in height and with an average width of 600mm (Fig. 8).

Fig. 7. Immediate soil stabilization by Cement grouting and plaster

Fig.8. Immediate support mechanism by 450-600mm brick work

Weep holes aligned staggered at 900 mm c/c using perforated 65-75mm diameter pipes are provided. The 450 -600mm thick brick work is plastered externally with 25mm thick rich cement mix 1:3 mix (Fig. 9). The above works were carried out to improve the better stability for the structure behind.

Fig.9. Plastered wall WIP

Meanwhile, to ensure the foundation strata the soil investigation was carried out with bore holes at three locations (Refer Fig. 10). From the bore-log details, it is seen that the upper most layer is back filled up to 3 3m from the ground level. It is followed by medium to highly weathered rock up to average depth 12 m below the ground level. The bottom most layer interacted is moderately weathered condition. The bore holes were terminated at 15 m below ground level. This showed that the foundation was laid on the highly weathered rock and was safe to resist the load of toilet block. The second and third layers are weathered to highly weathered condition which is underlain by moderately weathered rock deposits. It is clear that foundations of the structure were laid on the second and the third layer of the soil, and that it was in line with design proposed.

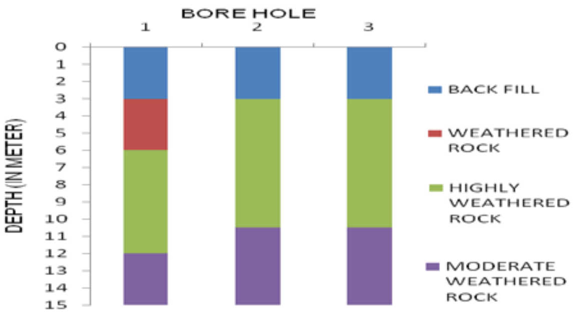

Fig.10. Bore Logs taken on the Site

The earth pressure calculations were made as per Rankine's theory. The stability of the retaining wall was checked for the Dead Load with Live Load combinations and found stable condition as the safety factors were within the permissible limits as per the prevailing codes of practice. The stability of the retaining wall was checked for the various loads including the structure surcharge and was found to be in equilibrium condition and the safety factors were within the permissible limits.

2.2 Field Condition Survey for the Toilet Block Structure

The fieldwork was done over a period 45 days at regular and periodic interval of time. Subsequently complete preliminary drawings, grid identification, measurements, noting and visual inspection were carried out. The toilet block structure was investigated in grid to grid for the ease in observations. Each element like column, beam and slab within the section was observed for a range of defects such as cracks, spalls, rust stains, crazing, dampness (electrical and water) etc. These defects were noted on the observation sheets. Each section observation was plotted on an individual observations sheet. Followed by field conditions the Non destructive tests were also carried out.

The structure was thoroughly inspected immediately after the collapse and monitored on regular basis for any distress and deviation from its normal course upto 45 days. Thereafter, progressive load test was carried out at the design load and the last reading for the load test was on the sixtieth day after the rehabilitation of the old retaining wall. No deviation was seen in the structural status of the reinforced concrete elements and the overall construction works for initial observation period of 60 days and further extended observation period of up to 201 days. The conditions were found to be satisfactory and no signs of distress /cracks/deformities were seen at all the levels during the monitoring period as well as the loading/unloading and pre and post progressive load test.

2.3 NDT and Progressive Load Tests

The USPV and Rebound Hammer Test were carried out as per the Indian Standards Codes of Practice and the results obtained are presented in Tables 1 and 2.

Table 1 Ultrasonic Pulse Velocity Test Reading

Levels	Location	Average Ultrasonic Pulse Velocity (Km/S)
Ground Floor	C-12	2.2
	C-1	2.4
	C-23	2.3
	C-13	2.5
	S/C1-C13	2.8
	S/C13-C3	2.8
First Floor	C-12	2.4
	B/C13-C2	2.9
	S/C12-C2	2.3
	C-23	2.3
	C12-C1	2.2
	C-14	2.8
Part Second Floor	C-34	2.6
	C-1	2.7
	B/C24-C34	3.0
Numbers		15
Average		2.5

<u>Progressive Load Test at Design Load</u>

A load test on concrete structure is required to check the serviceability of the structure either a strength deficiency and remedial measures are not fully known or the required dimensions and material properties for analysis are unavailable. Physical load test is more suitable to clarify the doubts about the shear or bond strength but it can also be used to check deficiencies related to flexure or axial capacity.

The toilet block structure was thoroughly inspected immediately after the collapse and monitored regularly for any distress and deviation from its normal course upto 45 days. Thereafter, the progressive load test was carried out as per ACI 437.2-13 at the design load and the last observation was recorded on the sixtieth day after the rehabilitation of the old retaining wall. The load test was carried out using external datum/bench marks; otherwise it was not possible by using conventional methods of installing strain gauges at the free end of the structure.

Table 2. Rebound Hammer Test Readings

Level	Location	R.No	Direction	Comp Strength N/mm^2
Ground Floor	C-1	35	Horizontal	34
	C-23	35	Horizontal	34
	C-13	35	Horizontal	34
	C-12	39	Horizontal	41
	S/C1-C13	35	Vertical Up	26
	S/C13-C3	38	Horizontal	39
First Floor	C-12	32	Horizontal	29
	B/C13-C2	30	Horizontal	25
	C-23	33	Horizontal	30
	B/C12-C1	31	Horizontal	27
	C-14	36	Horizontal	36
	S/C2-C12	35	Vertical Up	26
Part Second Floor	C-34	31	Horizontal	27
	C-1	32	Horizontal	29
	B/C24-C34	34	Horizontal	32
Numbers		26		
Average		22		

No deviation was seen in the structural elements. The conditions were found satisfactory and no signs of distress /cracks/deformities could be seen at all the levels.

Surveying instrument such as total station is used at top level of the structure to ascertain any temporary and permanent deformations as shown in Fig. 11.

Fig. 11. Total Station Method to observe the actual deflections/settlements

The loading was carried out by sand bags of equal weights as shown in Fig. 12. The loading was done in different phases as directed by the structural consultant. Observation was recorded before and after each phases of loading at various levels with the help of total station survey. After unloading the structure rebound capacity was checked to assess the deformation/deflection and /or settlement. The entire progressive load test was carried out as described below.

Fig.12. Loading First slab with sand bags representing the Design load

1. On the day 1 before loading the 6 numbers of points on the topmost location of the structure were decided and the existing R.L. of these points were recorded with the help of total station survey (Figs. 13 and 14).

Fig. 13. Six points selected at topmost level where the structure was desired to be tested

Fig. 14. Plan showing Six points selected at topmost level where the structure was desired to be tested

2. On Day 1 the part first floor was loaded (Fig. 11) with the help of packed sand bags representing the design load. The area under the all six columns influencing the load transfer to the retaining wall was considered. Thereafter, 4 sets of reading were recorded at an interval of 1 hour and the last reading of the day was taken after 3 hrs of initial reading.
3. On Day 3 the part second floor had been loaded with the help of packed sand bags (Fig. 15)

representing the Design Load. Again, 4 sets of reading were recorded at same time intervals.

Fig. 15. Loading second slab with sand bags representing the Design load

6. On Day 14, 5 sets of observations were noted on all the predetermined locations and represented graphically in Figs. 16 to 28.
7. The structure was opened for community usage and there after the readings were taken on 180th and 201st days and represented graphically with linear extrapolation method over the designed life of the building. For ease of presentation and understanding the same has been representated for 5 years in Figs. 16 to 28.

3.0 RESULTS & DISCUSSION

3.1 Summary of NDT Results

The NDT for assessing the quality of concrete was carried out by ultrasonic pulse velocity (UPV) method. The test was carried out on that portion of the concrete, which had not developed any significant cracking. Both direct as well as indirect methods of testing were used. All the velocities are represented in terms of direct equivalent velocity.

From the results it observed that the average Ultrasonic Pulse Velocity in the range of 2.2 to 3.0 km/s. Further from the detailed condition survey, the original concrete was found to be intact condition. From the results of rebound hammer tests conducted at various reinforced concrete elements showed that the Rebound Number varies from the range of 31 to 39 which shows that all structural elements are in sound condition.

3.2 Summary of Progressive Load Test Results

The results of Progressive Load Test carried out at the Design Load are presented in Figs.16 to 28.

The field tests at different load increments are plotted so as to observe the displacements or settlements with respect to time.

It can be seen that for all the six points of observations, the deflection versus time graphs are indicative of resilient properties. The behaviour has shown that it retain its original position after very negligible deflection. All the graphical variations concluded that there are no permanent deformities / deflections in the structure at the Design Load

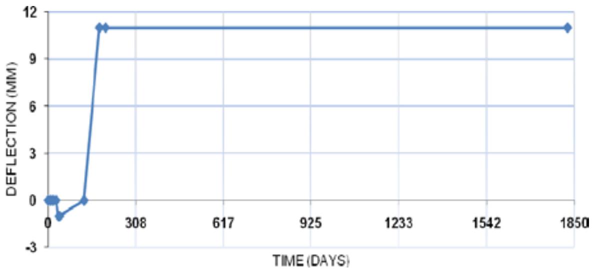

Fig. 16. Point 1 (Deflection v/s Time)

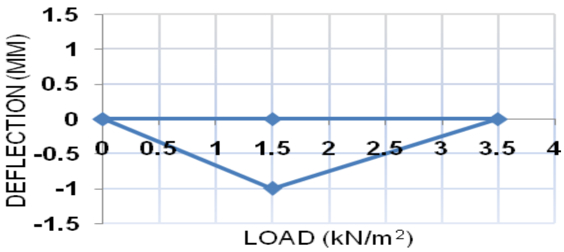

Fig. 17. Point 1 (Deflection v/s Load

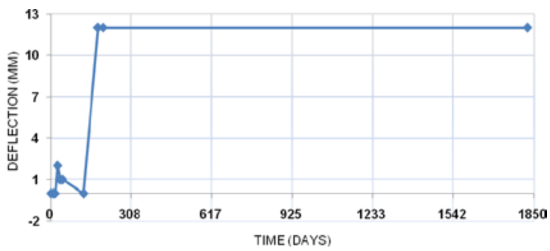

Fig. 18. Point 2 (Deflection v/s Time)

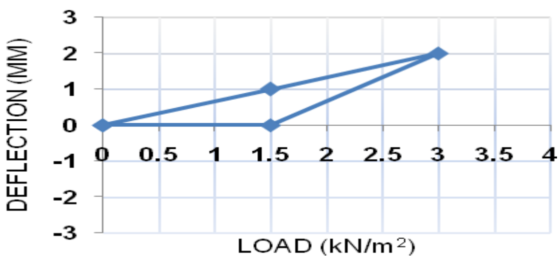

Fig. 19. Point 2 (Deflection v/s Load)

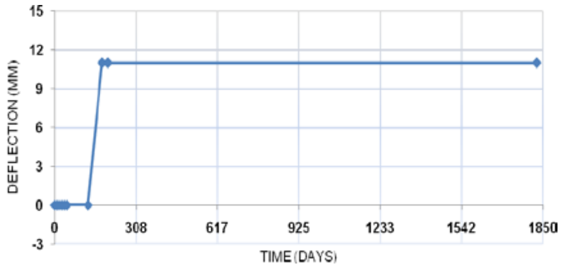

Fig. 20. Point 3 (Deflection v/s Time)

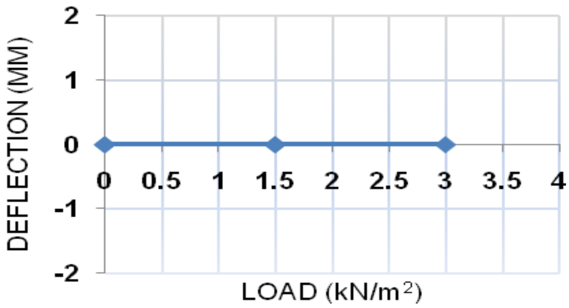

Fig. 21. Point 3 (Deflection v/s Load)

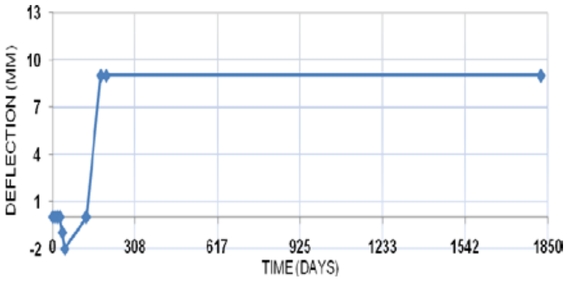

Fig. 22. Point 4 (Deflection v/s Time)

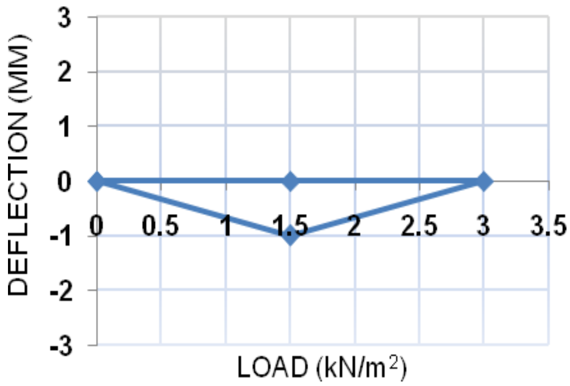

Fig. 23. Point 4 (Deflection v/s Load)

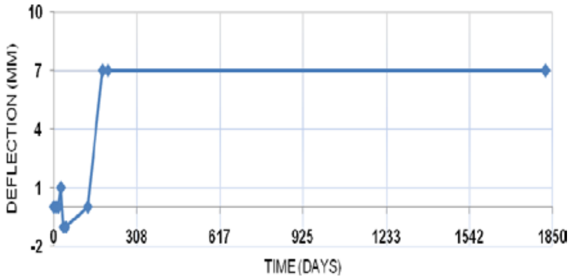

Fig. 24. Point 5 (Deflection v/s Time)

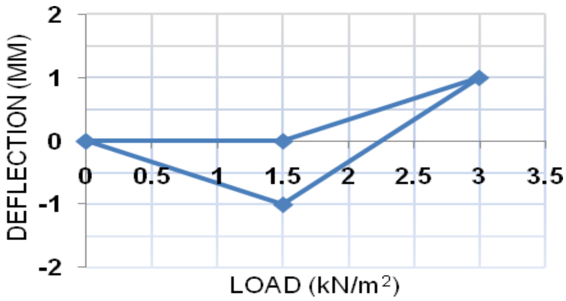

Fig. 25. Point 5 (Deflection v/s Load)

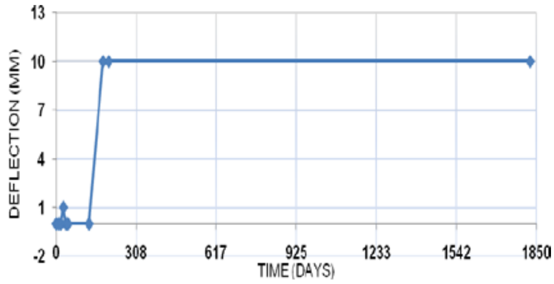

Fig. 26. Point 6 (Deflection v/s Time)

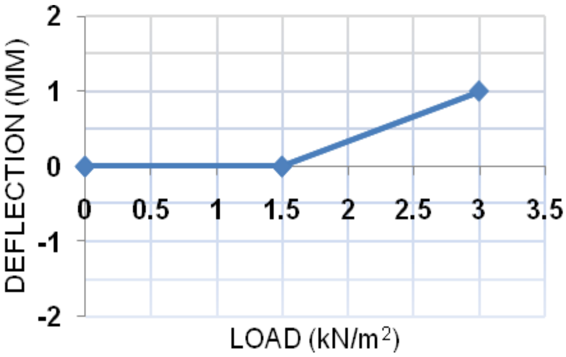

Fig. 27. Point 6 (Deflection v/s Load)

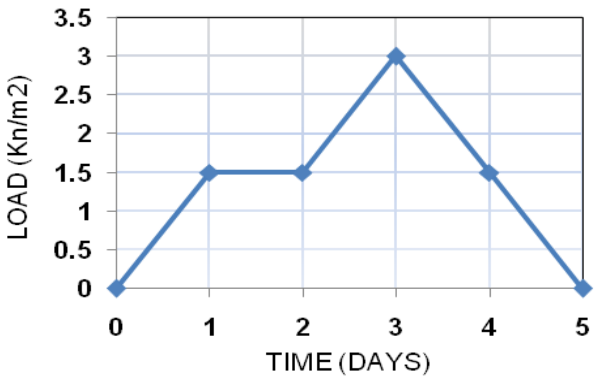

Fig. 28. All Points (Load v/s Time)

The finished condition of the wall is shown in the Fig. 29.

Fig. 29. Retaining wall after completion

4.0 CONCLUSIONS

The methodology was designed for successful rehabilitation of partly distress retaining wall supporting the toilet block structure. The partial slipped off of supporting soil beneath the retaining wall was stabilized using cement grouting subsequently supported by stepped brick retaining wall. The wall was safeguard against the excess pore pressure due to rain water using weeping holes. The distress or displacement in the toilet block was verified by NDT tests and progressive load test. The results of the tests are within the permissible limits as per Indian Standards. Moreover rehabilitated retaining wall is performing satisfactory without any distress or settlement after it has experienced the last rainy season. The structure was assessed for durability with the help of field test results extrapolated over the design period. The settlements were observed for short and long durations. The settlement in the short term period was entirely due to elastic deformation, and the long term settlement over the design period is almost negegible. The entire settlement is found within the permissible limit.

The rehabilitated structure is handed over to Municipal Corporation for the public use.

Acknowledgement

The successful rehabilitation of toilet block structure was completed due to all kinds of support from MCGM, B. Narayan and Associates, NGO - Pratha Samajik Sanstha and office staff of Aniruddha Nakhawa Structural Engineers and Project Consultants. Authors are very much thankful for their support.

References

ACI 437.2-13 Code Requirements for Load Testing of Existing Structures and Commentary

Fotso J.C., Ezeh, A.C., Madise, N.J. and Ciera, J., 2007. Progress towards the child mortality millennium development goal in urban sub-Saharan Africa; the dynamics of population growth, immunization, and access to clean water.*BMS Public Health,* 7.218-227.

IS 456 2010 Code of Practice for Plain and Reinforced Cement Concrete.

IS 13311 (Part 1) 1992 Non Destructive testing of Concrete - Methods of Test - Part 1 - Ultrasonic Pulse Velocity Test.

IS 13311 (Part 2) 1992 - Non Destructive Testing of Concrete - Methods of Test - Part 2 - Rebound Hammer

Marobhe, N.J., 2008. Critical review of water supply services in urban and rural areas of Tanzania. *Water Policy,* 10(1), 57-71.

Raza, H., Hussain, H. and Alibai, K., 1998. Seasonal Investigation of Drinking Water Quality.In *Sanitation and Water for All.*Ed. J. Pickford. Proc. 24th WEDC Conference, Islamabad, Pakistan.

Tiwari,P.sanitation.indiawaterportal.org/english/node/2918,*: Observer Research Foundation, Mumbai.*