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Instrumentation of a Road Tunnel Under Overburden Loading of a Four-Storied Building Structure, in Lonavla, Maharashtra, India

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Abstract: Maharashtra State Road Development Corporation Ltd. (MSRDC), India, is constructing a road tunnel 9 km long as part of the Mumbai Pune Expressway Missing Link Project in Maharashtra, India. The tunnel passes through heavily congested areas of Lonavla town wherein a number of building structures come near the alignment. However, a particular structure, a four-storied private building in Lonavla town falls directly on the center line of the alignment of the tunnel and just 40m above the tunnel crown. Extreme detailed geotechnical designs were required for the estimation of the load transmitted on the Class C type amygdaloidal basalt rock tunnel in order to dissipate the additional overburden pressure. FEM analysis was done for the design of initial and final supports. The tunnel was excavated in different parts heading, benching, invert and multi-stages, after each excavation part, the tunnel contour was secured by means of rock bolts, sprayed concrete, wire mesh and lattice girders. For building safety at ground level, the tunnel excavation pull was reduced to only 2m for lesser vibration. Monitoring instrumentation was done with Multi-Point Borehole Extensometers, Radial and Tangential Earth Pressure Cells, and Bi-reflex targets. The monitoring instrumentation study for the utmost safety of the building is explained in this paper in detail.

Keywords: Extensometer, Sensors, Pressure Cells, Bi-Reflex Targets, Instrumentation

1. INTRODUCTION

In earlier days there was very little emphasis on instrumentation, and lumpsum measurements were done only when failure looked imminent. But subsequently, because problems like rock bursts, high permeability, and support failures became very common in tunnel construction, instrumentation gained importance among designers and construction engineers. Moreover, in the NATM method of tunneling. which is based on the concept of "Design as you go", or rather "Design as you monitor", monitoring the displacements i.e., convergence and divergence of rock mass freshly excavated, through sophisticated instrumentation, has become an important and integral part of all major tunnel projects.

1.1 The problem: (See Fig 1) Out of the 9km long road tunnel (NATM type) passing thru Class C type amygdaloidal basalt rock, around 500m passes underneath the Lonavla town, and a particular four-story private building of size 23m x 10m falling right on the alignment with its foundation just 40m above the tunnel crown level. The building could not be shifted and neither the alignment could be diverted, so precau- tions in terms of design, construction, and monitoring were the only way ahead to safe- guard the building from getting damaged. Initial designs were done considering rock bolts and shotcreting, and tunnel excavation pull length was also reduced from the nor-mal 3.5m to 2m maximum.

Fig. 1 The building under study

1.2 The Design parameters:

Table 1 gives the geotechnical parameters of rock& Table 2 gives the Design parameters

Table 1 - Geotechnical strength parameters of Class C type rock:

Sr. No.	Description	Unit	Values
1	Cohesion Strength 'C'	MPa	1.16 to 1.41
2	Internal Friction Angle 'Φ'	Deg	45.12 to 40.29
3	Tensile Strength	MPa	-0.025 to -0.015, Say 0
4	Deformation Modulus, E_m	MPa	4603 to 2620

Table 2 - The initial Design parameters based on Q value = 4: (Ref Fig 2)

Sr. No.	Description	Values
1	Excavation Support Ratio (ESR) value for major road tunnel	1
2	Equivalent dimension D_c = Excavation Span, Diameter, Height (m) / ESR = 22.648m/1	22.648
3	Sprayed Concrete	100mm
4	Rockbolt Length	5.39m
5	Rockbolt Spacing	2.3m

Installed Rockbolt length of 6m at arch portion and 4m at side walls portion @ 2m c/c spacing.

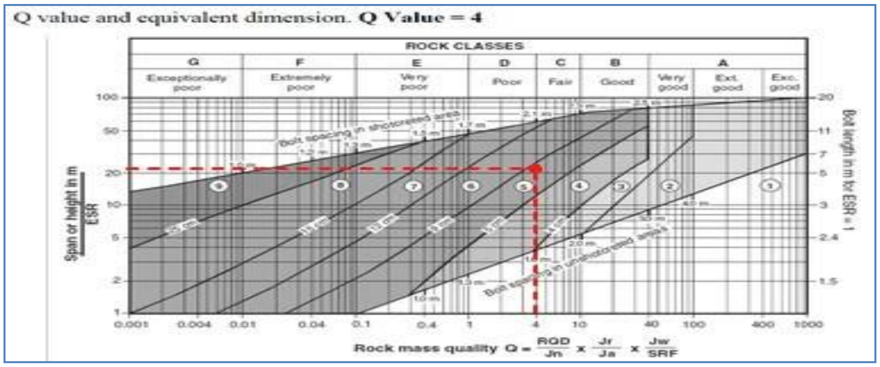

Fig. 2 Empirical chart for various rock classes

1.3 FEM Analysis

Geological software 'RocData' was used to arrive at properties of rock mass from data obtained from rock samples. Values obtained from RocData were used as input for FEM analysis. Phase2 FEM software was used for the FEM analysis and design of initial and final supports. A snapshot of the FEM model is shown in Fig 3. The analysis for support was done in twelve phases in Phase2, as follows:

a. Initialization of the stresses in strata.
b. Relaxation of Heading 1 – 60% of Rock mass
c. Excavation in Heading 1
d. Initial Support Installation in Heading 1
e. Relaxation in Heading 2 – 20% of Rock mass
f. Excavation in Heading 2
g. Initial Support Installation in Heading 2
h. Relaxation in Benching – 20% of Rock mass
i. Excavation in Benching
j. Initial Support Installation in Benching
k. Final Support Installation
l. Long-term with long-term rock mass modulus and long-term concrete modulus.

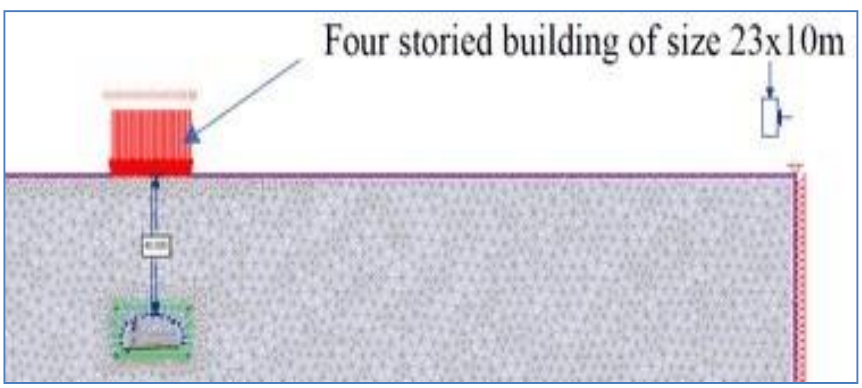

Fig. 3 FEM Model

1.4 FEM Analysis Results

Displacement value in Tunnel in Stage 12: 1.24e-002m=12.4mm
Displacement value in the ground in Stage 12: 3.90e-003m=3.9mm
Maximum Bending Moment in Sprayed Concrete: 5.15e-005MNm
Maximum Shear Force in Sprayed Concrete: 3.067e-004MN
Maximum Axial Force in Sprayed Concrete: 0.003MN
Maximum Axial Force in RockBolt: 0.063MN < RockBolt capacity 0.213MN
25mm diameter SN type RockBolt 2m c/c staggered spacing, 6m long at Arch portion and 4m long at Side Walls, found adequate.
50mm thick sprayed concrete M30 grade with Polyfibre as the initial layer and another 50mm as the final layer was found adequate.
The displacement pattern is shown in Fig 4.

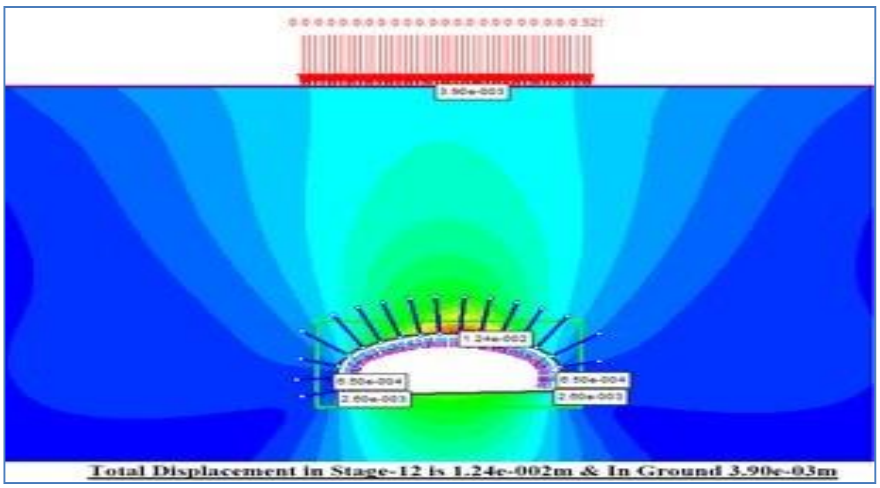

Fig. 4 Displacement pattern

Hence, for 40m overburden with building load, maximum deformation was found to be 12.4mm at the crown level and ground settlement as 3.9mm, hence found safe and no additional supports were found necessary. For building safety tunnel excavation pull was reduced to 2m instead of 3.5m in order to reduce the vibration. The above values now needed to be checked by installing proper monitoring instruments immediately after the tunnel excavation phase.

2.MONITORING AND INSTRUMENTATION

The purpose of instrumentation and its monitoring in such tunnel projects is to decide on the design of the final support system, to verify the assumptions made in initial designs, and to verify whether the performance is 'as predicted' or not. Data from the initial phase is used to improvise the support design in later phases. Instrumented data can help in deciding how fast construction can proceed without risk of failure and also can diagnose the flaws in the contractor's construction methodology. Monitoring the stability of excavation or adequacy of ground support also serves as a safety function by warning of the potential of ground failure thereby saving lives as well. The typically monitored parameters are convergence, crown settlement, floor heave, load in rock bolts/anchors, the stress in sprayed concrete, groundwater pressure, water pressure acting on lining, surface settlements, vertical and horizontal deformation of nearby buildings and other structures, vertical and horizontal deformation of ground at depth, etc. Instruments are selected based on reliability, and a comparison of the overall cost of procurement, calibration, installation, maintenance, reading, and data processing is to be made. The selection of location for the instruments should be based on the predicted behaviour of the tunnel. A practical approach to selecting instrument locations involves first identifying areas of particular concern like structurally weak zones or areas that are most heavily loaded. A predetermination shall be made of instrumentation readings that will indicate the need for remedial action, like the setting of awareness limits, attention limits, and alarm limits. Work flow chart of a geotechnical engineer is shown in Fig 5.

2.1 Multi Point Borehole Extensometer: (Ref Fig 6) It is used to monitor displace- ment or deformation in soil/rock at various depths. It normally consists of anchors, rods, protective tubes, and a vibrating wire (VW) displacement sensor. The anchors coupled to the rod are installed in the borehole. The anchors and anchor rods are referenced to stable ground, moving up or down as movement in the borehole occurs. This changes the tension of the vibrating wire in the VW transducer, which is transmitted through a cable to the readout unit.

Fig. 5 Flow chart

Fig. 6 MPBEx

2.2 Pressure Cells: (Ref Fig 7) A pressure cell is a type of sensor that converts stress/pressure into a measurable/readable electrical unit. By fixing pressure cells in the appropriate direction, the tangential and radial stresses in the tunnel crown/wall can be measured.

2.3 Bi-reflex Targets: (Ref Fig 8) It is a cost-effective method of recording deformations in tunnels. It consists of two parts; the bottom part is fixed permanently at the location where deformation is to be measured. When the deformation is to be measured, the top part is fixed to the anchor bolt and three-dimensional coordinates of the target are determined in an absolute reference system by optic trigonometric surveying of targets using a Total Station surveying equipment or similar.

Fig. 7 Pressure Cells

Fig. 8 Bi-reflex targets

3.INSTRUMENTATION READINGS:

Table 3 & 4 gives the readings of MPBExNo 1 & 2, Table 3 gives the readings of Pressure Cell, and Table 6 gives the read-ings of Bi-reflex targets.

3.1 Table 3 - Multi Point Borehole Extensometer No. 1, Chainage 11+200, Location – Crown (12-00).

Sen-sor	Depth from tunnel crown (m)	Initial Read-ing (Hz)	Read-ing af-ter 3 days (Hz / mm)	Read-ing af-ter 7 days (Hz / mm)	Read-ing af-ter 14 days (Hz / mm)	Read-ing af-ter 30 days (Hz / mm)	Read-ing af-ter 60 days (Hz / mm)	Reading after 90 days (Hz / mm)
1	4	4494.4	4493.3 / 0.06	4492.4 / 0.11	4492.3 / 0.12	4492.7 / 0.09	4492.3 / 0.12	4492.4 / 0.11
2	6	5000.1	5001.7 / 0.09	5001.9 / 0.10	5001.7 / 0.09	5002.3 / 0.12	5002.3 / 0.12	5002.2 / 0.11
3	8	4637.5	4635.8 / 0.09	4635.8 / 0.09	4635.8 / 0.09	4635.8 / 0.09	4635.2 / 0.12	4635.6 / 0.10
4	10	6031.2	6029.2 / 0.11	6029.5 / 0.10	6029.2 / 0.11	6029.1 / 0.12	6029.1 / 0.12	6029.5 / 0.10

3.2 Table 4 - Multi Point Borehole Extensometer No. 2, Chainage 11+200, Location – Crown/Wall (2-00).

Sensor	Depth from tunnel crown (m)	Initial Reading (Hz)	Reading after 3 days (Hz / mm)	Reading after 7 days (Hz / mm)	Reading after 14 days (Hz / mm)	Reading after 30 days (Hz / mm)	Reading after 60 days (Hz / mm)	Reading after 90 days (Hz / mm)
1	4	5610.1	5606.4 / 0.19	5606.4 / 0.19	5606.4 / 0.19	5605.7 / 0.23	5605.7 / 0.23	5606.4 / 0.19
2	6	4674.9	4676.7 / 0.09	4677.5 / 0.13	4677.9 / 0.15	4677.3 / 0.12	4677.9 / 0.15	4677.9 / 0.12
3	8	5557.2	5555.7 / 0.08	5555.2 / 0.11	5555.4 / 0.10	5555.4 / 0.10	5555.1 / 0.12	5555.2 / 0.11
4	10	5167.6	5166.2 / 0.07	5165.3 / 0.12	5165.8 / 0.09	5165.1 / 0.13	5165.1 / 0.13	5165.1 / 0.13

Sample calculation for conversion from Hz to mm:
(Final Reading in Hz – Initial Reading in Hz) X Gauge Factor = Displacement in mm.
Say, (5001.70 – 5000.10) X 0.05323 = 0.09mm

3.3 Table 5 - Pressure Cell, Chainage 11+200, Location – Crown/Wall (2-00).

Type	Initial Reading (Hz)	Reading after 3 days (Hz / kPa)	Reading after 7 days (Hz / kPa)	Reading after 14 days (Hz / kPa)	Reading after 30 days (Hz / kPa)	Reading after 60 days (Hz / kPa)	Reading after 90 days (Hz / kPa)
Radial	8196.00	8182.30 / 6	8180.60 / 7	8175.30 / 10	8175.30 / 10	8178.40 / 8	8178.40 / 8
Tangential	9808.50	9814.40 / 8	9816.30 / 11	9816.30 / 11	9816.30 / 11	9815.80 / 10	9815.80 / 10

Sample calculation for conversion from Hz to kPa:
(Final Reading in Hz – Initial Reading in Hz) X Gauge Factor X 100 = Pressure in kPa.
Say, (8182.30 – 8196.00) X 0.00462 X 100 = 6kPa

3.4 Table 6 - Bi-Reflex Target, Chainage 11+200, Location – Crown.

Reading Date	Easting	Northing	Elevation (m)	Easting (shift)	Northing (shift)	Elevation (change in mm)
Initial	334027.147	2072179.009	580.738	0.000	0.000	0
3 days	334027.146	2072179.010	580.739	0.001	0.001	1
7 days	334027.147	2072179.009	580.737	0.000	0.000	1
14 days	334027.150	2072179.008	580.740	0.003	0.001	2
30 days	334027.145	2072179.013	580.741	0.002	0.004	3
60 days	334027.146	2072179.011	580.740	0.001	0.002	2

All the obtained values were lesser than the designed Alert level (25mm), Action level (38 mm) & Alarm Level (50mm), hence no problem was faced or no redesign was required.

4. PROJECT SITE PHOTOS

Fig 9 shows settlement monitoring of the building structure. Fig 10 and 12 installations of MPBEx photos. Fig 11 a typical MPBEx read-ing recorded at the site.

Fig 9. Settlement observations in building

Fig 10. MPBEx installation

Fig 11. Typical MPBEX reading

Fig 12. MPBEx installation

5. CONCLUSION

All instrumentation data obtained were lesser than the awareness limit, attention limit, and alarm limits set by the Designer, hence no changes were suggested during construction, and the reinforcements done with rock bolts and sprayed concrete was found adequate. Some optical targets were fixed on the building as well, but no deformation was noticed. The vibration was also monitored near the building which was found very less and within limits.

References

1. ASTM D 4403 – 20, “Standard Practice for Extensometers Used in Rocks”.
2. Indian Roads Congress, SP-91-2019, Annexure-D, Cl. 3.6, “Tunnel Instrumentation”.
3. “Tunnel Engineering Handbook” by T R Kuesel, E H King, J O Bickel.
4. Maghsoudi A and Kalantari B (2014) "Monitoring Instrumentation in Underground Structures” Open Journal of Civil Engineering, Vol 4, No 2, 2014.
5. Naik R. Sripad (2017) "Role of Instrumentation and Monitoring in Underground Excavations". ISRM India Journal, 2017, Vol 6, Issue 2, 2018.
6. Lunardi G and Gatti M (2010), “Tunnel Monitoring System – A contribution for the preparation of guidelines” ITA-AITES World Tunnel Congress, 2010.