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Rock Anchors for Static Pile Load Testing: Considerations and Case Studies

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Abstract It is common practice in India to install rock anchors around test pile in order to obtain reaction for static load tests wherever competent rock is encountered at reasonable depths. Rock anchor design and installation require adequate attention as it is dependent on several parameters and checks. Authors have performed several static load tests across India with rock anchors up to test load of around 2000tons and also in various rock formations such as Basalt, Breccia, Tuff, Granite, Sandstone, etc. Competent rock levels also have been seen to be varied to great extent such as around 20 m from ground surface and such long free lengths offer several challenges including extension of strands equal to or more than ram stroke. Typically, for rock anchors in soft rocks, computed fixed length may be more than 10 m, and BS code 8081:1989 limits the fixed length to 10 m. In order to assess the rock anchor behavior for such condition where fixed length was more than 10 m, an effort was made to test the anchors to its full capacity and corresponding experience will also be summarized in the paper in the form of case history. This paper addresses rock anchor design philosophy including several checks required for appropriate rock anchor design, approaches for rock anchor design in soft rock, author's experience of rock anchor design and installation with various rock types across India, along with case studies. Paper will also highlight benefits and limitations associated with installation of inclined anchors for crown girder assembly.

Keywords Rock anchors · Pile load tests · Fixed length · Rock formation

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Introduction

Vertical load tests are commonly performed on pile foundations in order to assess pile capacities. The reaction can be obtained by kentledge or reaction piles or rock anchors in case of rock socketed piles. Kentledge type reaction requires huge setup, and the process is time consuming. It is suitable for piles with smaller test loads say up to 500-tons. As the test load increases, size of kentledge increases. This also increases the risk factors and complexities associated with the setup and field operations.

For moderate to high test loads (more than 500 tons) installation of reaction piles results in speedier completion and relatively safer operation. The test setup is compact as compared to kentledge, and it is very much suitable for sites with limited space such as Metro Rails. Testing with reaction piles is mainly applicable for friction piles, where contractor can install reaction piles along with test pile so that testing can be executed after completion of 28 days of pile casting resulting in time saving.

Sites where rock is present at reasonable depths, instead of installing reaction piles, testing can be performed by installing smaller diameter rock anchors by connecting them to girder assembly using HT strands. Installation of rock anchors requires adequate knowledge of Geotechnical Engineering and understanding of rock properties. Key benefits of testing pile with rock anchors include speedier construction of reaction setup, suitable for heavy loads

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(around 2000 tons) and early testing as it can be started once grout strength is achieved. Another advantage is as the rock anchor drilling rigs are quite compact, testing can be performed where space is major constraint. Although this test method offers lot of benefits that over other conventional methods, design and construction of rock anchor requires adequate attention so as to perform the vertical load test successfully. Following sections highlight the design philosophy to be adopted to rock anchors and various case studies demonstrating successful tests performed with rock anchors as well as challenges faced.

Design Philosophy of Rock Anchors

Rock anchors are installed to designed depths by drilling the holes of generally upto300mm diameter and inserting HT strands (typically 12.7 mm or 15.2 mm in diameter) followed by grouting with non-shrink grout up to top of fixed length. Rock anchors have free length (i.e., no grout zone and which is above fixed length) and fixed length (i.e., grouted zone contributing toward pullout resistance of the rock anchors). Guidelines for installation of rock anchors have been outlined in various codes worldwide, and important points are discussed below.

IS 2911 part IV [1] covers the load test on piles and allows use of rock anchors as reaction system in clause 7.1.3 (c). Rock anchors shall be installed at a distance of at least two times of pile diameter from the edge of the pile subject to minimum 1.5 m. IS 10270 [2] outlines guidelines for design and construction of rock anchors, and rock anchors installed for obtaining reaction for vertical load test are categorized as temporary anchors. The force on HT strands shall be limited to 70% of ultimate tensile strength of the strand and hence the quantity of the strands in each anchor shall be finalized accordingly. The fixed length of the anchor shall be decided after several checks such as bond strength between strand and grout, grout and rock as well as shear strength of rock. The bond strength between grout and rock shall be checked based on site specific rock properties such as unconfined compression strength (UCS) and also based on table provided in IS 10270. A relation is also established between UCS and ultimate bond strength in the code. Typically bond between grout and strand is much stronger, and hence is not a governing factor. However, a check on bond strength is desirable before finalizing the design.

In order to make sure that even if rock mass shears, the anchor system is still stable, pullout check shall be performed. The weight of sheared rock mass shall be more than the uplift force with minimum safety factor of 1.25 for temporary anchors. The designer shall be careful in selecting apex angle of rock mass (typically 60^0 in soft or highly weathered rock and 90^0 for moderately to slightly weathered rock) and also in selecting apex of rock wedge which shall be typically at the midpoint of fixed length and not at the base unless base plate is being used at the bottom [3]. Group action i.e., overlapping of rock masses of different anchors shall also be considered. Typically this approach is conservative as shear strength of rock in neglected, and the evaluation is purely based on weight of rock mass against applied anchor forces. It should be noted that, careful geotechnical data review, proper calculations of required checks is must. If adequate precautions are taken during designing of rock anchors, there are less chances of their failure during the test.

Considerations for Installation of Rock Anchors

Once rock anchors are designed as per guidelines or acceptable engineering practices, contractor shall exercise utmost care during installation of rock anchor so that they are constructed as per the design. Anchors shall be free of dirt or any other deleterious substance. Suitable spacers shall be provided at specified distance to ensure that strands are equally spaced. Coats of epoxy shall be applied on the fixed length portion followed by sprinkling of quartz sand to increase the bond. Anchors shall have arrangement into central portion so that grout tube is lowered all the way to the bottom at the time of grouting. The grout tube shall be checked to ensure that it is free of any foreign particles and grout can flow freely up to bottom of the drilled hole. Anchor shall be grouted only for fixed length zone, and it shall be ensured that grout is not present in free length zone so strands are free to elongate.

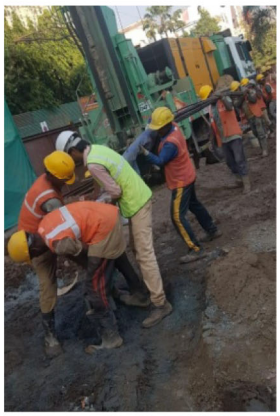
Once rock anchor installation is complete, girder erection and stressing of anchors can be performed after 7 days of grouting. It is authors' experience that the anchors are generally ready for stressing after 7 days. Following photographs presented as Fig. 1, illustrate the rock anchoring process.

Case Studies and Experiences with Rock Anchors

Authors have successfully performed several vertical load tests across India and gained invaluable experience with pile load testing with rock anchors. Rock anchors have been installed in variety of rocks including Basalt, Granite, Shale, Limestone, Sandstone, Breccia, etc. covering entire range of soundness of rocks. Following sections presents some of the case studies which shall summarize some interesting learnings from unique tests.

(a) Rock anchor drilling in progress

(b) Anchors made of strands



(c) Anchors being lowered in borehole

(d) Grouting in progress

(e) Rock anchors ready for stressing

Fig. 1 Rock anchor installation procedure

Rock Anchor Installation in Highly Weathered Rock

It has been seen that at several sites that core recovery of rock samples is very poor, and rock is highly weathered, and hence it is not possible to perform unconfined compression tests. In fact sometimes SPT is performed in such formations as rock is too weak. In such cases, it becomes challenging to assess fixed length of rock anchor without UCS values.

At a project site in Nagpur, borelog indicated weathered basalt underlain by weathered sandstone, and sandstone was underlain by weathered Gneiss. In basalt and sandstone formation, RQD was nil and core recovery was ranging from only 3–10%. SPTs were performed in Gneiss formation and blow counts were greater than 100 indicating refusal. Since UCS were not performed, rock anchors were designed based on allowable rock grout bond values as mentioned in Table 1 of IS: 10270, and fixed length was estimated to be 10 m. The test load was 750 tons, and hence 4 rock anchors were designed to provide required reaction. Just to make sure that design is conservative, a methodology applicable to design of piles in weak rock when core results are not available or material is highly fragmented was used to estimate fixed length as outlined in Appendix 5 of IRC 78 [4]. The analysis was performed considering weak rock formation, and this analysis resulted in fixed length of 14 m which was higher than IS guideline check mentioned above, and hence 4 rock anchors with 14 m fixed length were installed at site, and test was performed successfully. The design was also reviewed by third party consultant as per requirement of client. Photograph of pile load test is presented as Fig. 2.

For another site in Nagpur, test load on the pile was 1900tons. Subsurface conditions consisted of highly weathered sandstone underlain by completely weathered schist underlain by completely weathered Gneiss. SPTs were performed and indicated refusal blow counts. Core recovery and RQDs were not attempted probably because of presence of very weak rock. Hence an approach as mentioned above was adopted to estimate fixed length. As

Fig. 2 Vertical load test in progress at a site in Nagpur

rock was very weak, and load was very high, 8 rock anchors were planned with fixed length of 24 m. Here too, fixed length assessment was governed by IRC guidelines and hence more conservative.

For this load test, available plate girders were not suitable to carry such high load. Hence, crown girder was proposed which is very compact, and it was capable to carry the required test load. Benefit of crown type of girder includes its light weight compared to conventional girders and ideal at locations where space is limited. However, it requires installation of anchors at an inclination so that rock anchors are away from pile for at least 2 times pile diameter at rock level. Inclined rock anchor installation is challenging, and there is increased risk of hitting underground utility while drilling. Employing skilled driller with suitable rig is very critical. Maintaining designed angle and exact rock anchor location is also a challenge. During the drilling work of this test, driller had to install steel liner to deeper depths than he anticipated and faced difficulty during drilling due to collapse probably because of inclined drilling in overburden. Refer to Fig. 3 for crown girder setup. Rock anchors were installed successfully after dealing with several challenges, and test was performed successfully although the time frame for the entire operation was more as compared to conventional test setup and vertical rock anchors. Figure 4 presents photograph of pile load test with crown girder.

Vertical Load Test with Rock Anchors in Mumbai

For a project site in Mumbai, 23 m long test pile was installed having diameter of 1000 mm. Design load was 785 tons, and test load was 1962.5 tons (i.e., 2.5 times design load). Test pile was located in very compact area, and installation of rock anchors was extremely challenging. Initially 8 rock anchors were planned, and they were designed accordingly. Closest borelog to test pile encountered completely weathered rock at 5 m and highly weathered Tuffaceous Breccia from 8 m up to 19 m with RQD ranging from Nil to maximum 28. Slightly weathered Breccia was encountered underlying highly weathered Breccia with RQDs typically around 70. UCS results were available on samples collected at a depth of 12 m. UCS values were ranging from around 3.92 MPa (40 kg/cm^2) to 13.7 MPa (140 kg/cm^2). Free length was considered to be 12 m, and fixed length was 16.5 m which was quite long. The fixed length computation was governed by the criteria based on site specific UCS values. Lowest UCS was used in calculations as the rock formation was highly variable in terms of consistency and hence the design was conservative.

Eight rock anchors were installed at the site as per contractor's direction. After installation, during a revised review, the consultant raised concerns regarding fixed length of anchors. As per British Code [5], fixed length shall be limited to 10 m. IS code has not made such provision. Although we had enough past experience with similar tests, and design was conservative, consultant insisted for additional 4 anchors having similar configuration. This was done as required with increased time schedule and re-working of girder configuration to fit in 12 anchors within the setup. Eventually test was successfully completed and everyone was satisfied with the performance of pile as well as rock anchor system.

Once the test was completed, 8 out of 12 anchors were disconnected from the system and additional load was applied to check performance of rock anchors. As per original design, actual load on each anchor was 245 tons. Due to additional 4 anchors the actual load applied to each anchor was around 163tons during the test. Since the factor of safety in the design was at least 2.5, it was mutually decided to load the anchors up to 1.25 times the design load

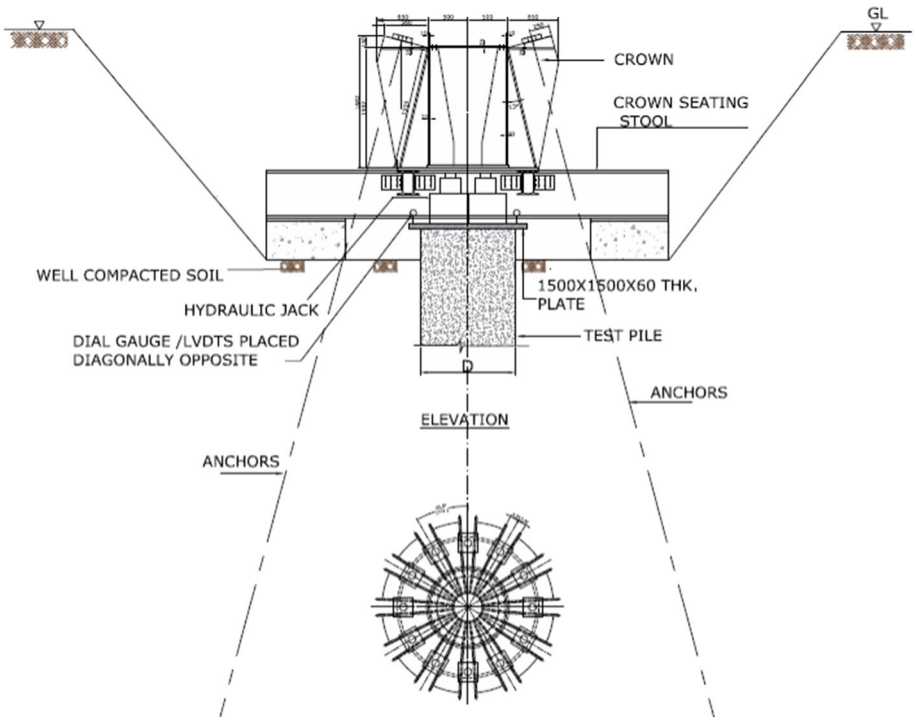


Fig. 3 Crown girder setup

Fig. 4 Vertical load test in progress with crown girder setup

of each anchor i.e., 300 tons to see if they get pulled out of ground. However, all four anchors carried the 300tons satisfactorily with only elastic extension of strands confirming that earlier design was conservative and was indeed a workable solution in the first place. A photo of load test setup is presented as Fig. 5 below.

Other Challenges with Rock Anchors

The biggest and common issue associated with installation of rock anchors is encountered, when subsurface conditions are significantly different than depicted in borelog on which rock anchor design is based. The issue is majorly experienced in Mumbai region the reason could be attributed to sudden geological changes in the region.

Fig. 5 Vertical load test in progress with 12 rock anchors

For a recent work, test pile was planned between two pier locations and contractor provided only one borelog and relevant rock test results specifying it is the closest borehole. The borelog indicated presence of hard basalt rock and hence rock anchors designed accordingly. However, while actual field work, Breccia was encountered instead of basalt. Field work was halted, and issue was escalated to contractor when he provided another borelog from another pier which indicated presence of breccia and more relevant to actual field conditions. Rock anchors were redesigned which resulted in significant increase in fixed length. Similar situations were faced for few other tests (e.g., rock encountered 2 m deeper than that indicated in borelog) as well and rock anchor design was altered as appropriate so as to make sure that their performance is not compromised during load test.

Another challenge associated with rock anchors is extension of strands equal to or more than jack ram stroke. This is common where free length is very long because rock is at deeper depths, and it allows extension of strands due to their elastic properties. For a project in Bangalore, free length was as high as 41 m, and test load was 1875 tons. The stroke of ram was 150 mm. The theoretical strand extension within free length zone was around 220 mm. It was anticipated in advance that this issue would occur during the test. In such cases, sufficient packing shall be made available so full load can be applied to the pile and the above stated limitation is overcome appropriately.

Concluding Remarks

Rock anchor are commonly installed to obtain reaction for static pile load test where rock is present. Due care shall be taken during design and installation of rock anchors so that they do not fail during testing. Design of rock anchors shall be as per codal guidance and also based on engineering judgment. The designer shall be experienced and shall properly communicate the design requirements to installation crew. The site crew shall also follow the guidelines provided by designer in order for satisfactory installation. Importantly, site person shall inform the designer in case he encounters different subsurface conditions than anticipated. The success of rock installation is highly dependent on team efforts between designer and site crew. The material such as strands, grout, etc., being used for installation shall be as per specifications.

Generally, rock anchors are designed based on site specific UCS data for rock samples. If rock is highly weathered, UCS data may not be available and in such cases other methods such as specified in IRC 78 can be adopted in addition to codal guidelines so as to make sure that design is conservative. Crown type girder setup is useful where space is constrain but inclined rock anchor installation is challenging. It is better to avoid it wherever possible and conventional plate girders shall be used for effective rock anchor installation. Authors have demonstrated that rock anchors perform satisfactorily even if fixed length is more than 10 m. More studies and case studies will be helpful in increasing the fixed length and subsequently increased use of rock anchors for testing. In such cases, adequate precautions shall be exercised so as to avoid failure. Higher free lengths results in excessive strand extension and adequate packing steel plates shall be arranged before the test itself. Even if rock anchor design and installation are challenging at times, authors have demonstrated that it is workable solution even for higher loads up to 2000 T.

References

1. IS 2911 (Part 4) (2013) Design and construction of pile foundations—code of practice. Part 4 load test on piles (second revision)
2. IS 10270: 1982 (Reaffirmed 2003) Edition 1.2. Guidelines for design and construction of prestressed rock anchors
3. Nayak NV (2012) Foundation design manual, 6th edn. Dhanpat Rai Publication, New Delhi
4. IRC:78-2014 (2014) Standard specifications and code of practice for road bridges. Section VII, foundations and substructures. Indian Road Congress
5. BS 8081:1989. British Standard Code of practice for ground anchorages