

A New Manual for Ground Anchor Inspection, Integrity Investigation and Remedial Measures

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Abstract

In the 50 years since the first ground anchors were used in Japan, the anchors have been used for various purposes in at least 30,000 projects. Some anchors constructed in early times have aged and lost their performance, resulting in slope deformation and exposure of broken anchor heads.

Establishing of efficient and rational maintenance scheme for existence anchors are necessary.

Various integrity investigation techniques and remedial measures have been proposed but have not been systematically organized.

Precious data on inspections and measures taken are scattered, and the lack of a system and data impede the efficient maintenance of anchor structures.

This paper describes our effort to improve maintenance of anchors publishing new manuals for Ground anchor maintenance.

Introduction

Ground anchors were first used in Japan in 1957 in a dam construction project. In the 50 years since then, anchors have been used extensively, including the application of permanent anchors in at least 30,000 projects exceeding a total length of 20,000 km, in order to stabilize natural and man-cut slopes for road and dam construction, improve structural stability, control floating of structures caused by underground water, etc.

Structurally, anchors stabilize slopes by introducing initial tensioning force during construction, which is gradually released over time through various mechanisms. Thus, anchors must not only be carefully designed and constructed but also vigilantly maintained, especially by monitoring residual tensioning force and checking integrity.

In the early years of anchor work, execution and rust-prevention technologies were still under development, and some of the anchors constructed during this period have aged and lost their performance, resulting in slope deformation and exposure of broken anchor heads.

Dangerous anchors can easily be found and treated if the construction drawings and

specifications and maintenance data are available. However, such references are scarce, and anchors are judged dangerous or safe based only on their type and construction period.

The relevant drawings, specifications, and construction records were not stored because anchors were regarded as an auxiliary method for stabilizing slopes.

Various integrity investigation techniques and remedial measures have been proposed but have not been systematically organized. Precious data on inspections and measures taken are scattered, and the lack of a system and data impede the efficient maintenance of anchor structures. A system for maintaining anchors needs to be constructed including inspection, integrity investigation, and remedial measures. In 2002, the Public Works Research Institute commenced studies on integrity investigation and remedial measures with the cooperation of the Japan Anchor Association (JAA) and conducted a joint study in FY2005. This paper describes resultant technologies for investigating the integrity of ground anchors and remedying damaged anchors.

Background of study

Actual state of existing anchors

In 1977, the Japanese Society for Soil Mechanics and Foundation Engineering (the present Japanese Geotechnical Society) established the “Earth anchor design and construction standard”. In 1988, the standard were revised into the “Ground anchor design and construction standard” 1), which requires the implementation of enhanced anticorrosion measures including double corrosion protection for permanent anchors. The revision accelerated the development of technologies for improving the corrosion resistance and reliability of each kind of anchor. Anchors that were designed and constructed based on the old standard (hereinafter referred to as the “old-type anchors”) are likely to contain insufficiently corrosion-resistant members. The total number of old-type anchors is not known since some data are unavailable, but a survey by the Japan Anchor Association gives an estimate of about 14,000 anchors, most of which were used for highway construction.

To understand the actual state of existing anchors, we conducted field surveys of anchors installed long ago and checked and categorized for major deformation and damage.

Manual for ground anchor inspection, integrity investigation and remedial measures

The objectives of manual preparation were to:

- 1) Systematically organize the concepts on inspection, integrity investigation and remedial measures needed for the rational and efficient maintenance of anchors;
- 2) Summarize and state the need for properly designing, constructing and maintaining anchors to retain their performance, in an easy to understand manner to ensure that the owners of projects, especially of public works, understand the need for maintenance; and
- 3) Emphasize the need for storing information throughout the service life of anchors to promote the development of technologies for investigating, designing, constructing, and maintaining anchors.

To accomplish the objectives, the manual describes the basic properties of anchors and fundamental concepts of maintenance in Chapters 1 and 2, enabling readers to understand the need

for maintaining anchors just by reading the first two chapters. As described above, the importance of maintenance is little understood by project owners, leading to failure of systematic budget allotment and loss of data and records. Chapters 1 and 2 were written to raise owner awareness. Chapter 3, which describes inspection, is also for owners, who usually inspect the anchors themselves in the case of highways. Chapters 4 and 5 describe integrity investigation and remedial measures assuming that the readers are owners who have read Chapters 1 to 3 and use the manual as a reference for discussing technical aspects with contractors. The basic concepts for appropriate method selection are described at the beginning of Chapters 4 and 5, followed by a description of integrity investigation methods and remedial measures, respectively, aiming to promote communication between owners and contractors. The general flow in Chapters 4 and 5 is a fundamental point to be understood by owners, and is stated as such in Chapter 2.

In Japan, design standard are established for each kind of anchor, but the technical standard for structures must also be considered since anchors also serve as supplementary members for stabilizing structures. In other words, anchors should be maintained by regarding them as part of the structure that they support. Chapter 2 explains that integrity investigation should be performed not only on individual anchors but also on the entire body consisting of anchors and supporting structure.

The following is an overview of the manual.

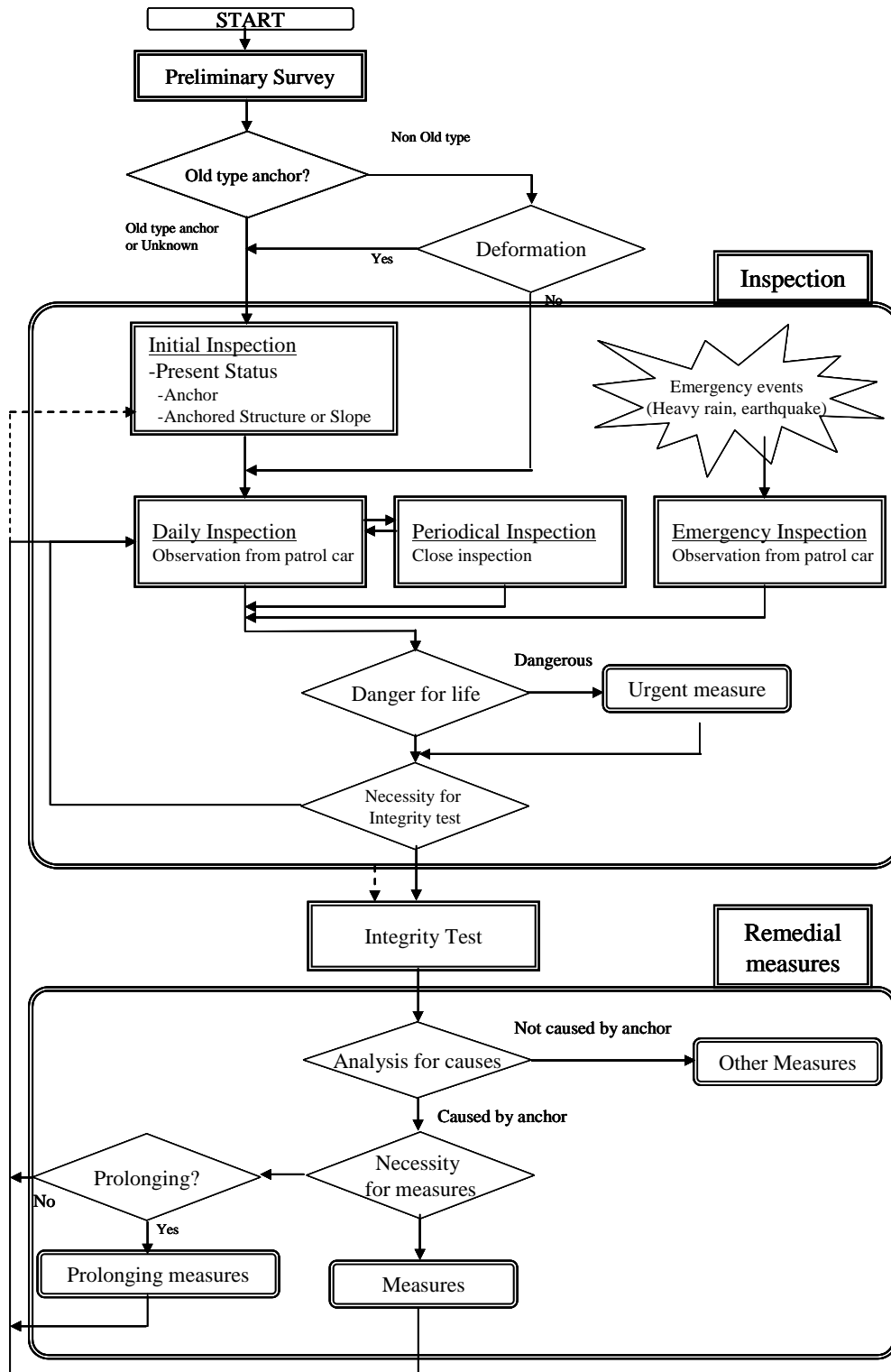


Fig.1 Flowchart for maintenance of anchor

Inspection of anchors

Anchor inspection is classified into periodical inspection to be performed as part of daily maintenance work and emergency inspection after storms, earthquakes and other such events. When any doubt arises as to the integrity of anchors, each anchor is investigated.

Preliminary survey

As a preliminary survey, references are studied before performing in-situ inspection of ground anchors. The objective of the preliminary survey is to collect the necessary data and information for maintaining the anchors, such as drawings and specifications of the anchors, structures, and slopes, maintenance records, and references on the peripheral topography.

When the preliminary survey reveals “old-type anchors”, initial inspection is to be conducted to understand the state of the anchors before performing ordinary inspection.

Initial inspection is also conducted on anchors other than “old-type anchors” if any deformation was previously found on the anchors, structure and/or slope. Preliminary survey involves studying references and should be performed for all anchors in principle. When references on the said anchors are not available due to disposal, etc., initial inspection is to be performed.

Initial inspection

During the initial inspection, the specifications of anchors, structure and slope and the state of the heads and pressure plates are inspected. For example, the need for anticorrosion treatment is judged from the year in which the anchor was designed and constructed, the title of the project, use and shape of head caps, etc.

Since initial inspection is conducted to supplement insufficient information and references, all anchors should be inspected, and the results recorded in inspection ledgers and retained for use in subsequent inspections. When the integrity of anchors is in question, an integrity investigation is performed to assess performance.

Ordinary inspection

There are daily, periodical and emergency inspections.

Daily inspection involves visual examination of anchors, anchor heads and pressure plates and other structures for any abnormality, in principle. Daily inspection is performed by the facility manager during patrols. For example, on ordinary national highways, daily inspection is conducted from vehicles and would be better if combined with annual or biannual periodical inspections.

Periodical inspection involves visual examination, in principle, and close inspection of hammering and measuring when necessary. Visual examination should, in principle, be conducted on all anchors, but close inspection can be reduced to 10% of all anchors or three or more extracted anchors. Anchors should be extracted so that different anchors are inspected every year and the state of the entire slope is understood by several periodical inspections.

Emergency inspection is performed upon notification from users as well as immediately after storms, earthquakes and other emergency events. In emergency inspection, safety must be quickly assessed, and all anchors should be visually examined. Anchors at which a slight deformation was found during daily and/or periodical inspection must especially be carefully examined on a priority basis.

When any abnormality that could affect integrity is found during an inspection, the anchors should be investigated for integrity. The results of all inspections should be recorded in ledgers and

retained.

Integrity investigation of anchors

Based on the inspection results, judgment is made as to whether or not the anchors need to undergo integrity investigation. Each anchor must be checked and, as described above, the anchors must also be assessed as a group of anchors constituting a structure. The manual describes this point in a manner that is especially easy to understand.

Even when an integrity investigation on individual anchors is not necessary, such as when no abnormality is found in any of the anchors but is found in the entire structure and/or slope, or when an anchor abnormality is so slight that there is no need for integrity investigation but the slight abnormality is concentrated in a certain range and is likely attributable to similar causes or spreads over a large area, integrity investigation is recommended.

The manual was prepared aiming to serve as a reference for assisting communication between owner and contractors, and includes the description of optional investigations and measures as well as obligatory work. For example, the manual recommends integrity investigation for anchors that were installed long ago and have not been examined for integrity and the exchange or repair of parts without integrity investigation when there is obvious damage and/or deterioration.

To better suit practical use, the manual was written to enable effective measures to be taken even under diverse limits, such as cost restrictions. For example, anchors demonstrating slight abnormality hinting of a slight integrity problem, but judged as not warranting integrity investigation, should be specifically monitored during subsequent inspections and quickly treated upon detection of increased abnormality.

Integrity investigations described in the manual include:

Detailed investigation of anchor heads

Detailed investigation of anchor heads involves checking the corrosion state of tension members and anchorages, water seepage from the back, tendon allowance length, and filling and degeneration state of rust-preventive oil as well as rough investigations such as visual examination and hammering (impact acoustics method).

Ultrasonic inspection

Ultrasonic inspection detects damage to tension members by irradiating ultrasonic waves and monitoring reflections, and is used as a preliminary investigation for assessing safety before lift-off tests, capacity tests and restressing, which are described below.

Lift-off test

Lift-off test involves measuring of residual load. The resultant load-displacement properties are used to investigate the apparent free length of the anchor and detect abnormalities. The data are also used to judge the need for investigating the back of anchor heads, conducting maintenance tests and restressing. Thus, lift-off tests would be better performed on all anchors subjected to integrity

investigation.

Investigation of the back of anchor heads

Investigation of the back of anchor heads is conducted on anchors for which the head metal can be removed by releasing tensioning force in order to check for corrosion of tension members, filling and degradation state of corrosion-inhibiting materials, condition of anticorrosion structures, and seepage of underground water.

Performance maintenance test

The performance maintenance test involves releasing the tensioning force of anchors, investigating the locking force of fixed anchors and the tensioning strength and apparent free length of tendons from the load and displacement properties. The data are used as a reference for integrity investigation.

Test of rust-preventive oil

The test of rust-preventive oil involves checking efflux and degeneration of oil by removing the head caps, sampling the oil by releasing the tensioning force and removing the distribution plates when necessary, and conducting chemical tests to examine air and water pollution caused by oil efflux and deterioration by heat and oxidization.

Monitoring of residual load

Monitoring of residual load, which is an index of anchor integrity, is performed through lift-off tests, performance maintenance tests, and sometimes, by installing axial load meters for continuous monitoring.

Supplementary investigations

Supplementary investigations are performed when anchor integrity is vulnerable due to chemical properties of the peripheral ground and underground water. The pH, acidity, and propagation of anaerobic sulfate-reducing bacteria are tested.

Remedial measures

For the various available remedial measures, the manual gives a systematic description of the technologies used so as to serve as a reference for technical communication.

Especially, the manual emphasizes the need for ensuring the performance of anchors throughout their design service life by implementing measures for those that have shown or possibly show a drop in performance to below the required level during inspection. Such measures were previously dismissed since anchors were believed to maintain the required performance level throughout their service life when they were installed.

Remedial measures should be taken by 1) considering anchors as a set when they have two or more factors in common regardless of the deterioration of the anchored structure and the fact that

each anchor is investigated for integrity; 2) designing repair and reinforcement measures by assessing the present behaviour, using the latest information and breaking away from the initial design conditions; and 3) thoroughly investigating the need for restoring and using anchors and combination with other appropriate methods.

When a problem is found on the entire slope before taking remedial measures, the causes should be removed first. If this is not possible, the appropriateness of using anchors should be investigated.

Drop in performance, including tensioning force, of anchors and improvement by remedial measures are schematically organized to systematically show the available measures.

Usually, the performance of anchors drops in the course of time, a typical example of which is tensioning force of fixed anchors. Anchors should retain the required performance throughout their service life, and remedial measures should be taken when an inspection identifies anchors that do not satisfy the requirements or ones predicted to show reduced performance within several years. Such anchors are to be treated by one of the following remedial measures based on their performance at the time of inspection and the remaining service life, and are either improved for durability, repaired, reinforced or renewed.

Improving durability

Anchors that demonstrate satisfactory performance at the time of inspection but are predicted to drop below the required level within the design service life are to be improved for durability. There are two methods: 1) decelerating the drop by removing the cause; and 2) improving performance to ensure it for the remaining service life.

Repairing and reinforcing

When the performance drops to a level unsuitable for service, the anchors are repaired and reinforced to improve their performance. Measures that are to be taken several times during the service life are called “repairing”, and those to be performed only once are called “reinforcing”.

Renewing

When anchorage performance is difficult to ensure by improving durability, repairing or reinforcing, new anchors are installed. This method is called “renewing”.

Prolonging life

Ensuring longer service of anchors that are sound at the time of inspection is called “prolonging life”. This can be achieved either by decelerating performance deterioration or improving performance as in improving durability.

Temporary measures and urgent measures

Temporary measures are defined as measures taken to retain the immediate performance of anchors when their performance level drops far below the required level and full-scale measures cannot be

taken for a while due to monetary restrictions, etc. The manual states that temporary measures, unlike ordinary measures, should be investigated in terms of economy and efficiency. The need for taking full-scale measures afterwards is also emphasized to call owners' attention to the fact that temporary measures are only temporary. Measures taken to ensure the safety of third persons against damage to structures and/or the safety of workers while taking emergency measures are called "urgent measures".

Training engineers involved in maintenance

The Japan Anchor Association issues licenses for ground anchor engineers aiming to cultivate engineers who use advanced technologies for anchor work and maintenance. To date, 3,038 ground anchor engineers have been certified and are involved in maintenance of anchors. The actualization of advanced anchor maintenance requires continuous training of highly capable engineers as well as preparation of manuals.

Conclusions

Methods for maintaining anchors have not been systematically organized, resulting in structures losing their function due to the drop in anchor performance and inappropriate measures causing economic loss.

The safety of structures that use anchors can be ensured and the maintenance cost can be reduced by proposing a flow of maintenance work ranging from daily inspection to integrity investigation and remedial measures. The proposed maintenance methods should be tested at sites and revised into more practical ones.

Standard for the design and construction of anchors have been established by the Japanese Geotechnical Society, but there is little information on maintenance. Since the effects of maintenance methods can be improved by recording data, installing axial force meters, etc. at the time of designing and installing anchors, the precision of the proposed maintenance methods would be enhanced by using them in practice and the results should be reflected in revised standard that cover the entire life cycle of anchors including design, construction and maintenance.

Just as standard on rust prevention of anchor materials promoted the development of rust-prevention technologies, the systematic organization of specific maintenance methods is expected to promote the development of technologies for maintaining existing anchors. There is high demand for structures that have easily exchangeable and repairable parts vulnerable to deterioration and technologies for assessing anchor integrity.

Acknowledgement

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References

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explanations, March 23, 2000

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