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RECOMMENDATIONS FOR MAINTENANCE OF CONCRETE STRUCTURES

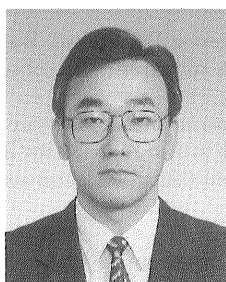
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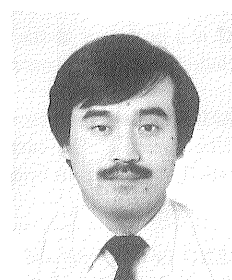
JSCE Subcommittee on Maintenance of Concrete Structures



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Maintenance of concrete structures has become essential for sustaining required functionality. The paper summarizes the Recommendations for Maintenance of Concrete Structures published by JSCE on Oct., 1995. The recommendations include basic concept of maintenance, prediction of deterioration, inspection technique, evaluation of deterioration, countermeasures toward deteriorated structures and maintenance records.

Keywords : category of maintenance, service life, durability, functionality, environmental impact, degree of deterioration, deterioration prediction, inspection, judgment of deterioration, repair, strengthening, record

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PREFACE

Concrete has been used for various structures which are exposed to mild or severe environments. Civil engineers believed that concrete structures had high durability and needed no maintenance work. In recent years, however, concrete structures have been known to deteriorate and maintenance has been really necessitated. Under the background of nowadays situation, Maintenance of Concrete Structures was put into the Appendix of the Construction Division of the Standard Specification for Design and Construction of Concrete Structures edited by JSCE in 1986. Concrete Committee, afterwards, organized two subcommittees on maintenance of concrete structures in 1988–1989 and in 1990–1991 (Chairman, Prof. Wataru Koyanagi). The present subcommittee has worked for submitting the recommendations for maintenance of concrete structures efficiently using the previous subcommittee's work results.

Recommendations for Maintenance of Concrete Structures includes Deterioration prediction, Inspection, Judgment and Measure toward deterioration (repair, strengthening). Principal concepts of the recommendations is as follows.

- ① Maintenance work is needed for concrete structures.
- ② The recommendations can be applied to both the structures designed on nowadays' Standard Specification for Design and Construction of Concrete Structures and those that are not designed. The recommendations are applicable to RC, PC and SRC members.
- ③ As concrete structures have to be maintained according as the importance levels of structures and the difficulty degree of the maintenance, the conception of the maintenance category was introduced.
- ④ In addition to the maintenance of the structures under usage, the items for the maintenance which have to be considered at design stage and construction stage are recommended. Importance of records after construction are especially emphasized.
- ⑤ The methods for deterioration prediction, assessment and judgment are described in detail under the present engineering level.

During the discussions for summarizing the recommendations, various comments and reports were submitted by the subcommittee members. Some of them are listed in the appendix.

When the basic concept and process of the maintenance is established, the next step will be to develop the management system for the concrete structures. The system will include prediction of the decrease of functionality and life time cost. The interval of inspection and the countermeasures will be decided systematically based on the deterioration prediction.

The subcommittee continued active work for over 3 years. I express my sincere gratitude to all the members who participated enthusiastically in its activities, and in particular to Dr. Ayaho Miyamoto and Mr. Yuichi Kaneko, secretaries of the subcommittee.

Hiroshi Seki
Chairman of the Subcommittee on Maintenance of Concrete Structures

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* Not included in this translation

CHAPTER 1 GENERAL

1.1 Scope

The recommendations (draft) set standards for the maintenance of concrete structures.

1.2 Terms and Definitions

Terms as used in the recommendations (draft) are defined as follows.

Maintenance: A general term for actions taken to maintain the original performances and functions of a structure above a given level; also referred to as preservation.

Preventive maintenance (category A): Maintenance of a structure intended to prevent deterioration of the structure; also called preventive preservation.

Corrective maintenance (category B): Maintenance of a structure in which maintenance measures are taken after deterioration of the structure has occurred; also called corrective preservation.

Observation maintenance (category C): Maintenance of a structure which is primarily dependent on visual inspection and permits deterioration to occur.

No-inspection maintenance (category D): Maintenance of a structure when it is very difficult or practically impossible to inspect the structure; also called preservation impossibility.

Length of use: The period of time during which a given structure is used.

Expected length of use: The period of time or number of years during which it is expected to be possible to use a given structure.

Service life: The length of time from the completion of a structure until the time when the structure is no longer usable because of failure to adequately perform its proper functions due to the deterioration of the structure itself or deterioration of its members.

Design service life: The length of time, specified at the time when a structure is designed, during which the structure or its members must adequately perform their proper functions (extracted from the Standard Specification for Design and Construction of Concrete Structures – Design–).

Remaining design service life: At the time a structure is inspected, the length of time left before the structure reaches the end of its design service life.

Functions of a structure (or of its member): The tasks in which a structure (or its member) performs with or without human intervention, according to the purposes of the structure or member.

Performance of a structure (or of its member): The ability in which a structure (or its member) exhibits with or without human intervention, according to the purposes of the structure or member.

Durability: The performance of a structure to resist gradual degradation of its performances and functions with the passage of time.

Functionality: All performances that a structure (or its member) has in relation to required functions except load bearing ability.

Load bearing ability: A performance of a structure that is assessed based on the load bearing strength of its members; another type of performance that a structure has in relation to its required functions.

Environmental impact: A performance of a structure that is related to the influence of the structure's deterioration on the environment.

Degree of deterioration: The extent to which the performance of a structure (or member) is degraded.

Inspection: A general term for actions taken to learn the current state of a structure.

Deterioration prediction: Foretelling the future degree of deterioration of a structure based on data regarding its design and construction and the results and records of inspections.

Measures toward deterioration: Steps taken to maintain a deteriorated structure (or member); measures toward deterioration include no action, intensified inspection, repair, usage restriction, strengthening, dismantling and removal, landscaping, functional improvement and functionality restoration.

Degree of possible impact on third parties: The probability that a structure may inflict damage on persons or materials in its vicinity as a result of concrete fragments and the like breaking away from it due to deterioration.

Repair: Any measure toward deterioration taken for a structure with the objective of arresting the deterioration of the structure or a member of the structure, restoring or improving the durability, or lowering the degree of possible impact on third parties; repair, however, does not have the objective of restoring or improving load bearing ability.

Strengthening: Any measure toward deterioration taken for a structure with the objective of restoring the load bearing strength of the structure or a member of the structure to, or higher than, the initial design level.

Functionality restoration: Any measure toward deterioration taken with the objective of restoring performances a structure has in relation to its required functions except its load bearing ability. Any measure toward deterioration to restore the load bearing ability of a structure, another type of performance a structure has in relation to its required functions, is distinguished as strengthening.

Function improvement: Any measure toward deterioration to raise the level of the functions of a structure to a required level to fulfill new needs.

Landscaping: Any measure toward deterioration taken when a structure is found to have great effect on its environment such as by impairing the beauty of the place.

Importance of a structure: A rank given to a structure according to the degree of the socioeconomic impact that would be caused by the cessation or degradation of its functions.

CHAPTER 2 BASIS OF MAINTENANCE

2.1 General

- (1) A concrete structure shall be adequately maintained throughout the entire length of its use, and its performance shall be kept at required level.
- (2) A concrete structure shall be maintained, in accordance with the categories of maintenance, by reasonably combining deterioration prediction, inspection, assessment and judgment, measures, and records regarding the structure.

2.2 Categories of Maintenance

Category or categories of maintenance for a structure shall be appropriately determined in view of the importance of the structure (or member), the degree of possible impact on third parties, length of use, environmental conditions, ease of maintenance, and so forth.

2.3 Maintenance and the Planning, Designing and Construction of Structure

- (1) In maintaining a concrete structure, records of the planning, designing and construction of the structure shall be appropriately used.
- (2) In planning, designing and constructing a concrete structure, it is desirable that its future maintenance be taken into consideration.

CHAPTER 3 DETERIORATION PREDICTION

3.1 General

- (1) In order to maintain a structure appropriately, deterioration of the parts and members of the structure shall be predicted.
- (2) In making the prediction, it is recommended that the performances which the structure or its member must have and the length of time for which they should retain these performances be made clear.
- (3) It is recommended also that relations between the performances of parts and members of a structure and their deterioration be ascertained, or that the effect of deterioration on each type of performance be made clear.

3.2 Deterioration Classified by Mechanism, and Factors of Deterioration

- (1) The types of deterioration of a structure shall be classified appropriately according to deterioration mechanism.
- (2) The factors of deterioration shall be classified as either extrinsic factors such as environmental and service conditions, or intrinsic factors such as design and construction conditions, and shall be determined correctly for the maintenance of the structure.

3.3 Basis of Deterioration Prediction

3.3.1 Inference of deterioration mechanisms

The deterioration mechanisms of a structure shall correctly be inferred from the phenomena and factors of its deterioration.

3.3.2 Formulation of deterioration development model

- (1) It is recommended that a model of the structure which appropriately incorporates its deterioration factors be used in order to quantitatively ascertain the development of deterioration.
- (2) Indices selected for predicting and assessing the deterioration of the structure (deterioration indices) shall be appropriate indices with known relations to deterioration mechanisms.

3.3.3 Level of deterioration prediction

The level of deterioration prediction regarding a structure shall be set in terms of the accuracy of the deterioration model, the importance of the structure or of its parts and members, and so forth.

3.3.4 Limit of deterioration

It is recommended that a structure's limit of permissible deterioration be set in view of the performances the structure or its members must have.

3.4 Deterioration Mechanism Model and Deterioration Prediction

3.4.1 General

For formulation of a structure deterioration mechanism model, the appropriate use of the factors and indices of structure deterioration described in this section is recommended.

3.4.2 Chloride induced deterioration

In predicting the deterioration of a concrete structure due to chloride ion, it is recommended that chloride ion contents on the surface and inside of the structure be treated as deterioration factors and that the depth from the surface where chloride ion concentration has reached its limit, the amount of corroded reinforcement or other items be used as deterioration indices.

3.4.3 Carbonation

In predicting the deterioration of a concrete structure due to carbonation, it is recommended that the mix proportion and curing conditions of the concrete, the construction and environmental conditions of the structure, and so forth be treated as deterioration factors and the depth of carbonation, the amount of corroded reinforcement, or other factors be used as deterioration indices.

3.4.4 Frost damage

In predicting deterioration of a concrete structure due to freezing and thawing, it is recommended that the water–cement ratio and air content of the concrete, outside air temperature, condition of water supply, and so forth be treated as deterioration factors and the depth of concrete damaged by frost be used as a deterioration index.

3.4.5 Alkali–aggregate reaction

In predicting the deterioration of a concrete structure due to alkali–aggregate reaction, it is recommended that the reactivity of aggregate, be treated as deterioration factors and the expansion of the concrete as a deterioration index.

3.4.6 Chemical concrete erosion

In predicting the deterioration of a concrete structure due to chemical erosion, it is recommended that the types and concentrations of the erosive substance and the water–cement ratio of the concrete be treated as deterioration factors and the eroded area and depth, the rate at which strength is declining, the amount of corroded reinforcement, and so forth be used as deterioration indices.

3.4.7 Fatigue

The deterioration of a concrete structure due to fatigue varies with the types of its members, the repeated loads that act upon it, and the types, intensities and frequencies of external forces that act on it. In predicting the deterioration of the structure, therefore, it is recommended that data on its members, repeated loads on the structure, and so forth be treated as deterioration factors and the state of cracks and deflection be used as deterioration indices.

3.4.8 Other

There are other types of deterioration of a concrete structure such as deterioration due to abrasion caused by cavitation and friction, cracks stemming from drying shrinkage, heat, and the alternation of moistening and drying. It is recommended that even these types of deterioration be predicted by using appropriate deterioration factors and indices.

3.5 Composite Deterioration

When a concrete structure suffers multiple types of deterioration, the composite effect as well as the individual mechanisms shall be considered.

CHAPTER 4 Inspection

4.1 General

Inspection of a structure shall be performed in order to learn accurately its state, discover deterioration and damage as early as possible, and maintain its functions.

4.2 Types of Inspection

4.2.1 General

- (1) Inspection of a structure shall be performed using the method and with a frequency appropriate for the maintenance category of the structure.
- (2) There are initial, daily, periodic, detail and extraordinary inspections, and appropriate types of inspection shall be selected from among these types based on the structure's importance and predictions of its deterioration.

4.2.2 Initial inspection

- (1) Initial inspection of a structure is generally conducted before or during the time the structure is being used, or after it has been repaired or strengthened, to predict its deterioration.
- (2) Items and parts of initial inspection shall be determined based on inferred deterioration mechanisms and the results of tests and inspections performed during its construction.
- (3) Initial inspection methods appropriate for the prediction of the structure's deterioration shall be adopted based on inferred deterioration mechanisms and the results of tests and inspections performed during its construction.

4.2.3 Daily inspection

- (1) Daily inspection of a structure is performed to know the location and time at which deterioration occurs and the state of deterioration of parts that are visually observable during a daily inspection survey.
- (2) The items, parts and frequency of daily inspection of a structure shall be determined based on the results of

prediction of its deterioration.

- (3) Daily inspection of a structure can be categorized as deterioration inspection by appearances using the naked eye, photographs, video recordings, binoculars, and so forth, and other inspections such as drive feeling.

4.2.4 Periodic inspection

- (1) Periodic inspection of a structure is performed to learn regularly the location and the state of deterioration of intricate parts of the structure that are difficult to observe in daily inspection.
- (2) The items, parts and frequency of periodic inspection for a structure shall be determined based on existing records of its maintenance and the result of prediction of its deterioration.
- (3) An appropriate method of periodic inspection shall be adopted for the structure based on the results of prediction of its deterioration.

4.2.5 Detail inspection

- (1) A detail inspection of a structure is performed when it has been found to be difficult to determine the degree of deterioration by visual inspections such as daily and periodic inspections; when the deterioration and damage of the structure or its members have been judged to be serious because of extensive development of deterioration; and when detailed data on deterioration are needed for repair and strengthening.
- (2) The items and parts of detail inspection for a structure shall be determined based on the results of daily and periodic inspections and the results of prediction of its deterioration.
- (3) Methods of detail inspection that serve the purpose shall be adopted for the structure.

4.2.6 Extraordinary inspection

- (1) Extraordinary inspection is performed to obtain quickly informations about abnormality of a structure in an emergency such as natural disaster (earthquake, storm or flood, for instance), fire, collision with a vehicle or ship, and so forth.
- (2) The items and parts of extraordinary inspection shall be determined according to the importance of the structure and the circumstances in an emergency.
- (3) Methods of extraordinary inspection that serve the purpose shall be adopted for the structure.

4.3 Inspection Process

4.3.1 General

Inspection of a structure shall be performed with visual method or with appropriate inspection equipment in view of its deterioration mechanisms.

4.3.2 Inspection for chloride induced deterioration

Inspection of a structure anticipated to be deteriorated due to chloride induced deterioration shall be more attentive to the concentration of chloride ions in and on the structure, the extent to which its reinforcement has corroded, and so forth.

4.3.3 Inspection for carbonation

Inspection of a structure anticipated to be deteriorated by carbonation shall be more attentive to the depth of carbonation, the extent to which its reinforcement has corroded, and so forth.

4.3.4 Inspection for frost damage

Inspection of a structure anticipated to be deteriorated by frost shall be more attentive to the depth to which the concrete is damaged by frost action and so forth.

4.3.5 Inspection for alkali–aggregate reactions

Inspection of a structure anticipated to be deteriorated by alkali–aggregate reactions shall be more attentive to

expansion of the concrete, cracks of the concrete caused by expansion, and so forth.

4.3.6 Inspection for chemical concrete erosion

Inspection of a structure anticipated to be deteriorated by chemical concrete erosion shall be more attentive to the depth of deterioration from the surface of the concrete, and so forth.

4.3.6 Inspection for fatigue

Inspection of a structure anticipated to be deteriorated by fatigue shall be more attentive to cracks and deflections of concrete structures and members, and so forth.

CHAPTER 5 Assessment and Judgment

5.1 General

- (1) Assessment and judgment of the deterioration of a concrete structure is performed according as two steps. One step is assessment and judgment based on the result of primarily visual inspection; another step is assessment and judgment based on the result of detail inspection.
- (2) With regard to a concrete structure, the comprehensive judgment shall be passed on whether the use of the structure can be permitted and the need whether repair and strengthening is needed by considering not only the results of assessing its durability, load bearing ability, functionality and environmental impact but also the importance of the structure or of its members.

5.2 Assessment

- (1) Based on the results obtained from the inspection of a structure, deterioration of its durability, load bearing ability, functionality and environmental impact shall be assessed by appropriate methods with levels of inspection and categories of maintenance taken into consideration. It shall be noted that the grade accorded to each inspection item as a result of inspection has a different degree of influence from that of others in the assessment of the durability, load bearing ability, functionality and environmental impact of the structure.
- (2) It is recommended that a comprehensive assessment of the deterioration of the structure be performed based on the stages of its deterioration revealed by the deterioration model described in Chapter 3, with grades awarded, as a result of inspection, to individual inspection items such as width of cracks and extent of reinforcement corrosion.
- (3) In the visual inspection of a structure, its durability, load bearing ability, functionality and environmental impact may be regarded as adequately sound when deterioration of the structure has not occurred.
- (4) In a detail inspection of a structure, its load bearing ability, functionality and environmental impact shall be assessed. Moreover, the durability of the structure shall be assessed by first narrowing down deterioration mechanisms to those with major effect, assessing the current degree of deterioration caused by these mechanisms, and then predicting the future development of deterioration.

5.3 Judgment

- (1) From the results obtained in the assessment of a structure by visual inspection, judgment shall be passed on whether detail inspection is required. Except when the structure is sufficiently sound, it shall be regarded as difficult to judge and be subjected to detail inspection, and at that time consideration of the results of predicting the deterioration of the structure and the importance of the structure shall be considered.
- (2) From the results obtained in the assessment of a structure by detail inspection, judgment shall be passed on what, if any, measures are required. This judgment shall be performed by comparing the results obtained in the assessment of its durability, load bearing ability, functionality and environmental impact with their limits. When a structure is judged to be in need of some measures, the measures shall be consistent with the degrees of degradation in the durability, load bearing ability, functionality and environmental impact.
- (3) After measures such as repair and strengthening have been taken, the effectiveness of the measures shall be confirmed through assessment and judgment of the measures by appropriate inspections.

CHAPTER 6 Measures Toward Deterioration

6.1 General

- (1) When a structure is assessed and judged as having a degradation of performance that is likely to pose a problem, appropriate types of measures shall be selected from among the following as required: intensified inspection, usage restriction, repair, strengthening, landscaping, functionality restoration, dismantling, removal, and so forth.
- (2) In carrying out selected measures, methods and materials appropriate to the causes and the degree of deterioration shall be selected, and a plan shall be established for implementing the measures.
- (3) When planning measures by choosing materials and methods, an objective level to which the structure's function is to be restored shall be established if required.
- (4) When deterioration that is likely to cause problems such as impact on third parties in the very near future is discovered, appropriate emergency measures shall be taken immediately.

6.2 Intensified Inspection

Intensified inspection of a structure, such as an increase in the frequency and items of inspection, shall be implemented based on the results obtained in the assessment and judgment of the structure and on its remaining design service life.

6.3 Usage Restriction

The extent and method of restriction on the usage of a structure, such as load restrictions, shall be determined through assessment and judgment of the structure, and, if required, through assessment and judgment by means of detail inspection.

6.4 Repair

Repair shall be done by choosing methods consistent with the causes of deterioration. A repair plan shall be framed by setting an objective level to which function is to be restored. Details of the procedure to be followed are stipulated in Chapter 7.

6.5 Strengthening

Strengthening of a structure shall be performed by choosing methods consistent with the causes of deterioration. A strengthening plan shall be framed by setting an objective level to which function is to be restored. Details of the procedures to be followed are stipulated in Chapter 8.

6.6 Landscaping

In landscaping a structure by such means as painting it or placing additional concrete on it, landscaping and implementation plans shall be framed by considering the surrounding scenery and the structure's functions, remaining design service life, and so forth.

6.7 Functionality Restoration and Function Improvement

Functionality restoration and function improvement of a structure shall be designed with objective levels and plans for implementation.

6.8 Dismantling and Removal

Dismantling and removing methods suitable to the structure shall be selected in view of its environment, public safety, the disposal of debris after dismantling, the term of the work, and so forth.

CHAPTER 7 Repair

7.1 General

- (1) Repair is a maintenance measure taken with regard to a structure to restrain further deterioration, to eliminate possible impact on third parties and to restore durability.
- (2) Repair of a structure shall be preceded by investigation of the structure's deterioration, if necessary.
- (3) Repair activity shall have an established plan and be executed according to the plan, and shall be subjected to appropriate control and inspection during and after the activity.
- (4) Repair of a structure should eliminate the causes of its deterioration. However, when complete elimination is impossible, measures shall be taken to restrain further deterioration.

7.2 Repair Plan

- (1) In planning repair of a structure, repair methods consistent with the causes of its deterioration shall be selected based on the results obtained in prior investigation.
- (2) In planning repair of a structure, an appropriate level of repair shall be set in view of the structure's maintenance category, importance, remaining design service life, economy of repair, and so forth.
- (3) In planning repair of a structure, repair activities shall be accurately designed and an implementation plan shall be framed.

7.3 Execution of Repair

- (1) Repair of a structure shall be executed by considering the environment and the time of the repair work.
- (2) In repairing a structure, the bonding of concrete to section restoration materials, surface protection materials, crack-filling materials, materials for anodes in cathodic protection and so forth shall be firmly secured by adequate backing treatment.
- (3) The performance of section restoration materials, surface protection materials, crack-filling materials, and materials for anodes in cathodic protection shall be secured by adequate curing after the repair work has been executed.

7.4 Repair Control and Inspection

- (1) Materials used in repair of a structure shall be inspected with appropriate frequency; their quality shall be standardized and control criteria established.
- (2) Repairs shall be inspected during the work, using established items and criteria for controlling the repair work.
- (3) After the completion of repair work, a completion inspection shall be performed to confirm that the repair work was performed in conformity with the repair plan, and the results of the inspection shall be put on record.

CHAPTER 8 Strengthening

8.1 General

- (1) Strengthening is a maintenance measure taken to restore or improve the load bearing ability of a structure.
- (2) Strengthening shall be preceded by an investigation of the structure's deterioration, if necessary.
- (3) Strengthening activity shall have an established plan and shall be executed according to the plan, and shall be subjected to appropriate control and inspection during and after execution.

8.2 Strengthening Plan

- (1) In planning the strengthening of a structure, an appropriate level of strengthening shall be set in view of the structure's maintenance category, importance, remaining design service life, and so forth.
- (2) Economical methods of strengthening shall be selected, based on the results of inspection, assessment and judgment, from among those which are capable of being used to attain a specified level of strengthening, by considering structural conditions, working conditions and the durability of the structure.
- (3) In planning the strengthening of a structure, strengthening shall be accurately designed and an execution plan shall be framed.

8.3 Execution of Strengthening

- (1) Strengthening of a structure shall be executed by considering the environment and the time of the work.
- (2) Integration of strengthening materials with existing members of a structure shall be attained by adequate backing treatment.
- (3) The performance of strengthened members of a structure shall be secured by adequate curing after the strengthening work.
- (4) The existing members of a structure shall not be damaged by strengthening work.

8.4 Strengthening Control and Inspection

- (1) Materials used in strengthening shall be inspected with appropriate frequency; their quality shall be standardized and control criteria established.
- (2) The results of strengthening shall be inspected during the work using established control items and criteria.
- (3) After the completion of strengthening work, a completion inspection shall be performed to confirm whether the work was done in conformity with the strengthening plan.

CHAPTER 9 Records

9.1 General

In order to maintain a concrete structure properly, records of the results of designing, work execution, inspection, assessment, judgment, repair, strengthening and so forth shall be created and retained.

9.2 Retention Period of Records

- (1) The maintenance records of a structure shall be in principle retained as long as the structure is in use.
- (2) It is desirable that the records be kept even after the structure has gone out of use, as reference materials for maintaining other structures.

9.3 Method of Recording

The maintenance records of a structure shall be kept in a given way that allows them to be read with ease.

9.4 Recording Items

The items to be recorded regarding a structure shall be in principle major data; the environment; maintenance categories; the results of deterioration predictions; inspection plans and the results of inspections; the results of assessments and judgments; and plans for providing measures and the results of measures provided, in addition to records in the form of general drawings and photographs.