Executive Summary

Development of Standards for Inspection, Evaluation and Repair of Existing and Damaged Structures

Submitted to

Department of Public Works and Town and Country Planning

by

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1. Background

Structures after construction which include structures which are new, old, left without use, damaged by disasters or fire, aged, overloaded, fatigued, or deteriorated by any other reasons, require inspection and evaluated for proper maintenance processes which may be protection, repair, strengthening or reconstruction. However, there is still no comprehensive standards or guidelines for practicing maintenance in Thailand, causing the current practice not in same level of standard or same direction or sometimes high cost. The launching of this standard is useful to upgrade and standardized the maintenance practice, resulting in increased safety and reduced cost for the maintenance.

2. Procedure

The following procedures are conducted in this project.

- Study and analyze the existing regulations, laws, standards or technical documents, related to inspection, evaluation, repair and strengthening of structures, of Thailand.
- Study and analyze the existing international regulations, laws, standards or technical documents, related to inspection, evaluation, repair and strengthening of structures, of at least 5 countries of regions.
- Collect case studies of inspection, evaluation as well as repair and strengthening as follows.
  - At least 20 cases of structures for inspection and evaluation
  - At least 20 cases of structures for repair and strengthening
- Analyze the data of case studies
- Propose a regulation and a standard and revise them according to comments received from an expert committee and comments from a technical hearing.
- Draft manuals for inspection and evaluation, repair, strengthening of structures.

- Study impacts on adopting the proposed regulation and standard as well as recommend solutions.
- Conduct a technical hearing session on adoption of the regulation and standard, having at least 100 participants.
- Summarize the results of the study

Remarks:

(1) This study covers only reinforced concrete structures, prestressed concrete structures and steel structures

(2) This study does not cover seismic evaluation and strengthening.

3. Study on Regulations and Standards of Thailand

We studied the followings.

3.1 Building Control Laws

Laws concerning building control include building control acts, ministerial regulations, announcements of ministry of interior and local governments.

3.1.1 Building control acts 1979

3.1.2 Ministerial regulation 1984

3.1.3 Ministerial regulations regarding building inspection

3.1.4 Ministerial regulations for determination of building categories, criteria, methods and conditions on inspection of design and calculation of members in buildings.

3.1.5 Ministerial regulation for determination of criteria on issuing permission for construction and modification of incomplete buildings that have been affected by economic crisis

3.1.6 Ministerial regulation on control of signboards or supporting structures for signboard installation following building control acts

3.1.7 Ministerial regulation no. 12 (1985)

3.1.8 Ministerial regulations for determination of criteria on permission of modification of buildings for the purpose of seismic strengthening

3.2 Standards of the Department of Public Works and Town and Country Planning

3.2.1 Standard for durability and service life design of concrete structures (DPT 1332-50)

3.2.2 Standard for measuring movement of buildings (DPT 1552-51)

3.2.3 Standards for non-destructive tests of reinforced concrete structures (DPT 1501-51 to 1507-51)

3.2.4 Standard for dynamic load test of piles (DPT 1252-51)

3.2.5 Standard for checking integrity and uniformity of piles by seismic test (DPT 1551-51)

3.2.6 Standard for practice of concrete repair (DPT 1901-51)

3.2.7 Standard for strengthening of reinforced concrete structures by using fiber-reinforced composite (DPT 1508-51)

3.2.8 Standard for inspection of welding of structural steels by nondestructive methods (DPT 1561-51 to 1565-51)

3.2.9 Inspection of welding of structural steels by ultrasonic method (DPT 1562-51)

3.2.10 Inspection of welding of structural steels by using penetrating substances (DPT 1564-51)

3.2.11 Inspection of welding of structural steels by using rays (DPT 1565-51)

3.3 Standards of Engineering Institute of Thailand

3.3.1 Standards for reinforced concrete by strength method (EIT 1008-38)

3.3.2 Manual for building safety inspection

3.3.3 Manual for inspection of cracks; causes and solutions

3.3.4 Failures of building; causes and solutions

3.4 Manuals of Thailand Concrete Association

3.4.1 Manual for inspection and evaluation of structural performance of reinforced concrete structures

3.4.2 Training document on maintenance and repair of reinforced concrete structures

3.5 Standards of Thailand Industrial Standard Institute

3.5.1 Industrial product standard on rust protection coatings (TIS 2387-2555)

4. Study on International Regulations and Standards (for Reinforced Concrete Structures)

4.1 United State of America

Various regulations and standards established by International Code Council (ICC), American Concrete Institute (ACI), American Society of Civil Engineers (ASCE) and International Concrete Repair Institute (ICRI) were studied as follows.

4.1.1 International Code Council (ICC)

Fifteen codes and standards are currently available. Some are selected for this study.

4.1.1.1 International Existing Building Code (IEBC) for existing buildings

4.1.1.2 International Building Code (IBC) for new construction

4.1.2 American Concrete Institute (ACI)

Manual of Concrete Practice (MCP) covers standards, specifications, manuals and reports in which some contents concern design, inspection, evaluation, repair and strengthening of damaged structures as follows.

4.1.2.1 ACI 562-13 Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-13) and Commentary

4.1.2.2 ACI214.4R-03 “Guide for Obtaining Cores and Interpreting Compressive Strength Results”

4.1.2.3 ACI 228.1R-03 “In-place methods to estimate compressive strength”

4.1.2.4 ACI 503R-93 (Reapproved 2008) — Use of Epoxy Compounds with Concrete

4.1.2.5 ACI 503.1-92 (Reapproved 2003) — Standard Specification for Bonding Hardened Concrete, Steel, Wood, Brick, and other Materials to Hardened Concrete with a Multi-Component Epoxy Adhesive

4.1.2.6 ACI 503.2-92 (Reapproved 2003) — Standard Specification for Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive

4.1.2.7 ACI 503.4-92 (Reapproved 2003) — Standard Specification for Repairing Concrete with Epoxy Mortars

4.1.2.8 ACI 503.5R-92 (Reapproved 2003) — Guide for the Selection of Polymer Adhesives with Concrete

4.1.2.9 ACI 503.6R-97 (Reapproved 2003) — Guide for the Application of Epoxy and Latex Adhesives for Bonding Freshly Mixed and Hardened Concretes

4.1.2.10 ACI 224.1R-07 - Causes, Evaluation, and Repair of Cracks in Concrete Structures

4.1.2.11 ACI 222R-01 - Protection of Metals in Concrete Against Corrosion

4.1.2.12 ACI 201.2R-08 - Guide to Durable Concrete

4.1.2.13 ACI 440.2R-02 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

4.1.2.14 ACI 216R-89 Guide for Determining the Fire Endurance of Concrete Elements

4.1.3 American Society of Civil Engineers (ASCE)

ASCE provides some standards related to structural maintenance as follows.

4.1.3.1 ASCE/SEI 7-10—Minimum Design Loads for Buildings and Other Structures

4.1.3.2 ASCE/SEI 11-99—Guideline for Structural Condition Assessment of Existing Buildings

4.1.4 International Concrete Repair Institute (ICRI)

ICRI established many guidelines for repair of concrete structures as follows.

4.1.4.1 ICRI No. 210.3-04—Guide for Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials

4.1.4.2 ICRI No. 320.2R-09—Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces

4.1.4.3 ICRI No. 340.1-06—Guideline for the Selection of Grouts to Control Leakage in Concrete Structures

4.1.5 NACE International

NACE International (National Association of Corrosion Engineers) has published various documents related to corrosion of steels, for both repair and protection, as follows.

4.1.5.1 NACE 01101—Electrochemical Chloride Extraction from Steel-Reinforced Concrete—A State-of-the-Art Report

4.1.5.2 NACE 01102-02—State-of-the-Art Report: Criteria for Cathodic Protection of Prestressed Concrete Structures

4.1.5.3 NACE 01104 Electrochemical Realkalization of Steel-Reinforced Concrete—A State-of-the-Art Report

4.1.5.4 NACE 01105-05—Sacrificial Cathodic Protection of Reinforced Concrete Elements—A State-of-the-Art Report

4.1.5.5 NACE RP0 2 9 0 - 0 0 —Standard Recommended Practice— Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures

4.1.5.6 NACE SP0107-07—Electrochemical Realkalization and Chloride Extraction for Reinforced Concrete

4.1.5.7 NACE SP0390-09 (formerly RP0390)—Maintenance and Rehabilitation Considerations for Corrosion Control of Atmospherically Exposed Existing Steel-Reinforced Concrete Structures

4.2 International Standard Organization (ISO)

4.2.1 Technical Committee 71

International Organization for Standardization (ISO) has Technical Committee 71 (TC71) that is responsible for concrete works. TC71 has a subcommittee (ISO/TC 71/SC 7) which has been working on the following standards related to maintenance of concrete structures.

4.2.1.1 ISO 16311-1:2014 Maintenance and repair of concrete structures -- Part 1: General principles

4.2.1.2 ISO 16311-2:2014 Maintenance and repair of concrete structures -- Part 2: Assessment of existing concrete structures

4.2.1.3 ISO 16311-3:2014 Maintenance and repair of concrete structures -- Part 3: Design of repairs and prevention

4.2.1.4 ISO 16311-4:2014 Maintenance and repair of concrete structures -- Part 4: Execution of repairs and prevention

4.2.1.5 ISO/TR 16475:2011 Guidelines for the repair of water-leakage cracks in concrete structures

4.2.1.6 ISO 16711:2015 Seismic assessment and retrofit of concrete structures

4.2.2 Technical Committee 98

ISO/TC 98 is responsible for structural design. ISO/TC 98 has a subcommittee, ISO/TC 98/SC 2 on structural reliability, that established the following related documents.

4.2.2.1 ISO 2394:2015 General principles on reliability for structures

4.2.2.2 ISO 13822:2010 Bases for design of structures -- Assessment of existing structures

4.2.2.3 ISO 13823:2008 General principles on the design of structures for durability

4.2.3 Technical Committee 135

ISO/TC 135 is responsible for nondestructive tests.

4.3 Japan

The following acts, standards and practices were studied.

4.3.1 Building Standard Law (BSL)

4.3.2 Mansion Aptitude Management Law

4.3.3 Japan Society of Civil Engineers

Japan Society of Civil Engineers (JSCE) offered standard specifications on design, materials and construction as well as maintenance for structures. One of them is the "Standard Specification for Concrete Structures –Maintenance".

4.3.4 Japan Concrete Institute

JCI has produced manuals and trained for certifying engineers who are working in the area off concrete in 2 categories, Concrete Engineers and Concrete Diagnosis Engineers.

4.3.5 Architectural Institute of Japan

Architectural Institute of Japan (AIJ) has published the following maintenance related documents.

4.3.5.1 Test Methods for Quality Control and Maintenance of Reinforced Concrete Buildings, 2007

4.3.5.2 Recommendations for Diagnosis and Repair Methods of Fire-damaged Buildings, 2010

4.3.5.3 Japanese Architectural Standard Specification for Reinforced Concrete Work JASS5, 2009

4.4 The International Federation for Structural Concrete (FIB)

Standards of fib which are related to inspection, evaluation, repair and strengthening of structures are as follows.

4.4.1 FIB Bulletins No.3: Textbook on Behavior, Design and Performance Volume 3: Durability - Design for Fire Resistance - Member Design - Maintenance, Assessment and Repair - Practical Aspects

4.4.2 FIB Bulletins No.14: Externally bonded FRP reinforcement for RC structures

4.4.3 FIB Bulletins No.17: Management, maintenance and strengthening of concrete structures Technical

4.4.4 FIB Bulletins No.22: Monitoring and safety evaluation of existing concrete structures

4.4.5 FIB Bulletins No. 46: Fire design of concrete structures - structural behavior and assessment

4.5 European Union

EN 1504 is a set of standards concerning products and systems for protection and repair of concrete structures, which is divided into 10 standards as follows.

4.5.1 EN 1504-1 Part 1: Definitions

4.5.2 EN 1504-2 Part 2: Surface protection systems

4.5.3 EN 1504-3 Part 3: Structural and non-structural repair

4.5.4 EN 1504-4 Part 4: Structural bonding

4.5.5 EN 1504-4 Part 4: Structural bonding

4.5.6 EN 1504-5 Part 5: Concrete injection

4.5.7 EN 1504-6 Part 6: Anchoring products

4.5.8 EN 1504-7 Part 7: Reinforcement corrosion protection: coatings for reinforcement

4.5.9 EN 1504-8 Part 8: Quality control and evaluation of conformity

4.5.10 EN 1504-9 Part 9: General principles for the use of repair materials and systems

4.5.11 EN 1504-10 Part 10: Site application of products and systems, and quality control of the Works

4.6 Asian Concrete Federation (ACF)

Asian Concrete Federation (ACF) has launched 10 standards and guidelines as follows.

4.6.1 An example of seismic performance examination for RC building design according to the Architectural Institute of Japan (AIJ) Guidelines, 2001

4.6.2 Vietnam National Standard TCXDVN 318:2004 - "Concrete and Concrete Reinforced Structures - Guide to Maintenance", 2004

4.6.3 Guidelines for maintenance and rehabilitation of concrete structures against chloride induced deterioration, 2004

4.6.4 Guidelines for materials and construction based on Japanese Standard Specifications, 2005

4.6.5 Guidelines for the design of reinforced concrete buildings against fire actions, 2007

4.6.6 Guidelines for designing transverse confinement reinforcement of reinforced concrete columns against seismic actions, 2009

4.6.7 Guidelines for the seismic assessment and retrofit of concrete structures, 2010

4.6.8 Guidelines for maintenance and rehabilitation of concrete structures subjected to carbonation-induced deterioration, 2011

4.6.9 Guidelines for materials and construction of concrete structures based on the Thai standard specifications, 2014

4.6.10 Guidelines for durability and service life design of concrete structures based on the Thai standard

5. Study on International Regulations and Standards (for Steel Structures)

5.1 United State of America

5.1.1 American Welding Society (AWS)

AWS D1.1/D1.1M:2010 "Structural Welding Code – Steel" was selected for this study, consisting of the followings.

5.1.1.1 Standard for inspection of welding

5.1.1.2 Standard for welding repair

5.1.1.3 Standard for strengthening and repair of existing structures

5.1.1.4 Standard for preheating before welding

5.2 European Union

5.2.1 EN ISO 12944-2 Corrosion protection of steel structures by protective paint systems. Part 2: Classification of environments (ISO 12944-2: 1998)

5.3 Japan

5.3.1 Japanese Architectural Standard Specification (JASS)

JASS 6: 1993 "Japanese Architectural Standard Specification, JASS 6: Structural Steelwork Specification for building Construction" was studied. The standard gives specifications for construction of steel structures, which covers a part on inspection, evaluation and repair.

5.3.2 Road bridge periodic inspection procedure Ministry of Land, Infrastructure and Transport Road Bureau

5.4 International Standardization and Organization (ISO)

5.4.1 ISO 4628: Paints and varnishes —Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance

ISO 4628 and ISO 4928 contain contents related to inspection and evaluation of coatings.

5.5 Australia and New Zealand

5.5.1 Australia Standard (AS) and New Zealand Standard (NZS)

Standards which were selected for this study are AS/NZS 1554.1:2014 "Structural steel welding. Part 1: Welding of steel structure" and AS/NZS 1554.5:2014 "Structural steel welding. Part 5: Welding of steel structures subjected to high levels of fatigue loading".

5.6 Assessment of existing steel structure: Recommendations for estimation of remaining fatigue life (JRC European Commission)

It is mentioned in this report that fatigue is a specific case of deterioration which is necessary for performance assessment of steel bridges.

6. Summary of the Study on International Standards

Table 6.1 (for concrete structures) and Table 6.2 (for steel structures) summarize the international standards which were studied in sections 4 and 5, respectively.

Table 6.1 List of studied international standards for concrete structures

Region	Standard organization
USA	International Code council (ICC)
	American Concrete Institute (ACI)
	American Society of Civil Engineering (ASCE)
	International Concrete Repair Institute (ICRI)
	NACE International
International	International Standard Organization (ISO)
Japan	Building Standard Law (BSL)
	Mansion Aptitude Management Law
	Japan Society of Civil Engineering (JSCE)
	Japan Concrete Institute (JCI)
International	The International Federation for Structural Concrete (FIB)
Europe	European Union
Asia	Asian Concrete Federation (ACF)

Table 6.2 List of studied international standards for steel structures

Region	Standard organization
USA	American Welding Society (AWS)
Europe	European Union
Japan	Japanese Architectural Standard Specification
	Road bridge periodic inspection procedure Ministry of Land, Infrastructure and Transport Road Bureau
International	International Standard Organization (ISO)
Australia and New Zealand	Australia Standard (AS) / New Zealand Standard (NZS)
European Union	JRC European Commission

From the study of Thai and international documents, the following observations can be summarized.

1) Thailand still does not have acts or regulations which are related to inspection, evaluation, repair and strengthening of structures.
2) In Thailand, though there are some standards, a comprehensive standard that cover, in principal, overall processes which include inspection, evaluation, repair and strengthening still does not exist.
3) In Thailand, though there are some standards related to inspection, repair materials and strengthening using some materials, there are still lacking of manuals for recommending the proper materials and methods for practices.
4) Direct adoption of international standards is not the best solution as it can cause problem due to different local conditions.
5) There are varieties of patterns and concepts of international standards. Properly referring to those standards is an important consideration. There is no necessity to just refer to only one standard.

Therefore, it is beneficial to establish regulations and a comprehensive standard as well as manuals concerning inspection, evaluation, repair and strengthening for Thailand, so that referencing and practices can be done with the same standard and in the same direction.

7. Case Studies

Efforts were spent to select case studies that cover various causes and types of damage and deterioration as well as degrees of severity as shown in Table 7.1 and 7.2. From the case studies, the following issues can be observed.

So far, practices on inspection, evaluation, repair and strengthening of structures in Thailand have been conducted by following the same practices as before. Materials and methods still do not have much varieties. Mostly foreign standards and specifications are used for references.

Therefore, it is beneficial to establish regulations and a comprehensive standard as well as manuals concerning inspection, evaluation, repair and strengthening for Thailand, so that referencing and practices can be done with the same standard and in the same direction. It is also beneficial to publish manuals of practices for inspection, evaluation, repair and strengthening as they can be use as references for selecting proper materials and methods. They can also be used as references for teaching engineering students as well as for training practical engineers.

Table 7.1 Summary of cases study of inspection and evaluation of 22 cases of concrete and steel structures

Case	Location	Building type	Structure type	Age (years)	Member	Damage	Inspection method	Damage level
1	Saraburi	Industrial factory	Reinforced concrete	-	Column	The damaged area was repaired by patching but did not work. Cracks re-occurred.	Rebound hammer, carbonation depth, sulfate and chloride contents in concrete, service temperature and temperature stress analysis during service	2
2	-	Apartment	Reinforced concrete	21	Column, beam and slab	Cracking and rust stain on the beam surface along the rebar direction	Rebound hammer, covert thickness and rebar location by cover meter, chloride content in concrete, carbonation depth	2
3	Rayong	High voltage transmission towers	Reinforced concrete	8	Column	Damage of coating during construction	Corrosion degree following ISO4628, coating thickness based on ASTM D7091, thickness of steel after corrosion	2
4	Bangkok	Hospital	Reinforced concrete	-	Slab	Shrinkage cracking on concrete surface found since before opening the building to service due to load	Analysis of cracking due to shrinkage and load	2

Case	Location	Building type	Structure type	Age (years)	Member	Damage	Inspection method	Damage level
5	Samutsakorn	Hospital	Reinforced concrete	7	Slab	Fire damage, cracking found under slabs	Rebound hammer, thermograph, melting of objects and materials	2
6	Bangkok	Water tank	Reinforced concrete	21	Water tank	Cracking along rebar direction under slab, rust stain, efflorescence, cracking radiating around the column head	Rebound hammer, cover thickness, chloride content at the rebar location, half-cell potential	2
7	Rachaburi	Office	Reinforced concrete	7	Slab	Cracking under slabs, probably due to shrinkage	Rebound hammer, cover thickness and rebar location, half-cell potential	2
8	Rayong	Cooling tower	Reinforced concrete	19	Column	Cracking found along the rebar direction in columns	Rebound hammer, cover thickness, chloride content at the rebar location, carbonation depth	2
9	Chonburi	Hotel conference room	Reinforced concrete	7	Slab	Cracking under slabs	Rebound hammer, load test	2
10	Samutprakan	Cooling tower	Reinforced concrete	18	Slab	Cracking scattering in random directions on surface of footing	Rebound hammer, temperature due to heat source from the	2

Case	Location	Building type	Structure type	Age (years)	Member	Damage	Inspection method	Damage level
							steam tunnel above the footing, rebar corrosion test due to chloride and carbonation	
11	Samutprakan	Cooling tower	Reinforced concrete	18	Column and beam	Cracking along the rebars in column, rust stain	Rebound hammer, cover thickness, chloride content at the rebar location, half-cell potential, vibration frequency and acceleration	2
12	Trang	Product warehouse	Reinforced concrete	30	Column	Fire, cracking in beams, spalling, distortion of structures	Compressive strength, estimation of duration and maximum temperature of fire exposure	4
13	Bangkok	Office	Reinforced concrete	18	Beam and slab	Fire, cracking in beams, shear crack found due to rebar strength reduction from fire effect, concrete spalling, distortion of steel beams	Concrete core strength, observe color change of concrete, Microstructural microscope (SEM-BSE), Thermogravimetric Analysis (TGA)	3
14	Northeast	Footing of wind turbine	Reinforced concrete	-	Footing	Parallel cracking in footing (Thermal cracking expected)	Analysis of thermal stress comparing between the	1

Case	Location	Building type	Structure type	Age (years)	Member	Damage	Inspection method	Damage level
							designed mix proportion and the mix proportion with 20 kg increase of cement content.	
15	Bangkok	Footing of elevated expressway	Reinforced concrete	11	Footing	Parallel cracking in footing	Compressive strength, unit weight, uniformity by Ultrasonic Pulse Velocity, Modulus of elasticity, number and location of rebars, cover thickness, crack depth, existing load carrying capacity, microstructural investigation by SEM-EDX	2
16	Samutprakan	office	Reinforced concrete	-	Beam, column and slab	Fire, color change of concrete, many shear cracks in beams	Compressive strength by ultrasonic pulse velocity	5
17	Chonburi	Power plant	Structural steel	-	Beam and column	Corrosion of steel structures, blistering, gliding	Steel thickness and coating thickness measurements	4
18	Pathumthani	Signboard	Structural steel		Steel member	Low quality welding, rusting, blistering, gliding	Steel thickness measurement	2

Case	Location	Building type	Structure type	Age (years)	Member	Damage	Inspection method	Damage level
19	Pathumthani	Signboard	Structural steel	-	Steel member	Low quality welding, loss of bolts, washers and nuts, steel cross section loss	Steel thickness measurement, coating thickness measurement	2
20	Rayong	Port pier	Structural steel	-	Column	Rust, blistering, gliding	-	3
21	-	Office	Reinforced concrete	-	Column, beam and slab	Diagonal cracks in walls and cracks at the wall-column joints	Survey of building plane Survey verticality of columns	1
22	-	Shopping mall	Reinforced concrete	-	Column and beam	Obvious settlement, diagonal cracks in walls, cracks near column heads and rebar corrosion found	-	4

Table 7.2 Summary of cases study of repair and strengthening of 20 cases of concrete and steel structures

Case	Building type	Member type	Age (years)	Cause of damage	Damage level	Repair method	Strengthening method
1	Cooling tower in power plant	Column	10	Chloride induced corrosion	3	Concrete Jacket	-
2	Cooling tower in power plant	Column	10	Chloride content at the steel location is higher than the critical chloride content	2	Apply corrosion inhibitor	-
3	Cooling tower in power plant	Column	10	Chloride content at the steel location is higher than the critical chloride content	2	Electrochemical protection	-
4	Wind turbine structure	Footing	Just completed	Thermal cracking due to change of mix proportion by increasing cement content	2	Not necessary to repair cracks	-
5	Parking floor	Slab	-	- Deflection is larger than the allowable limit	4		External prestressing

Case	Building type	Member type	Age (years)	Cause of damage	Damage level	Repair method	Strengthening method
				- Results measured by an accelerometer showed high values			
6		Footing	Just completed	Thermal shock during insulation curing by sudden raining	2	Injection using elastic filling material	-
7	Lighthouse	Column	40	Corrosion of rock-filled steel pipe and wave impact covering	3	Concrete jacketing under seawater	-
8	Office	Slab	20	Damages found during improvement of waterproofing system. Leakage found under slabs (breaking of prestress tendons)	4	-	CFRP strengthening
9	Parking	Beam	20	Need to strengthen the deteriorated structures as the structures had been in service for longer than 20 years, also need to increase service load.	Actually 2 but identified	-	CFRP strengthening

Case	Building type	Member type	Age (years)	Cause of damage	Damage level	Repair method	Strengthening method
					3 as service load increase was required		
10	Port pier	Column	10	Cracking of piles caused by accidental ship collision on slabs above the piles	4		Concrete Jacketing
11	Office	Slab	1	Impact from dropping object from the floor above, causing cracking in RC beam in 3rd floor	2	Crack Injection	-
12	Condominium	Slab and column	45	Rebar corrosion	3	Ferro cement Jacketing	-
13	Condominium	Beam and slab	45	Rebar corrosion	3	Cement Jacket	-

Case	Building type	Member type	Age (years)	Cause of damage	Damage level	Repair method	Strengthening method
14	Port pier	Column	30	Corrosion of steel piles caused by loss of the surface coating due to abrasion and erosion	2	Coating repair of structural steel	-
15	Factory	Column	20	Change of usage (installing new machines)	-		Steel Jacketing
16	Water tank	Wall		Water leakage at the concrete wall of the waste water treatment structure	3	Injecting Pu-Foam and Epoxy	-
17	Cooling tower	Column	10	Chloride content at the steel location is higher than the critical chloride content	2	Corrosion protection by sacrificial anode	-
18	Port pier	Steel column	-	Corrosion in steel piles due to surface coating damages during construction	2	Apply steel surface coating	-
19	Factory	Slab	5	Drying shrinkage cracking	1	No need	-
20	Cooling tower	Wall	15	Chloride content at the steel location is higher than the critical chloride content	2	Crack filling using epoxy (a low cost preliminary	-

Case	Building type	Member type	Age (years)	Cause of damage	Damage level	Repair method	Strengthening method
						repair, plan for intensive repair in the future)	

8. Proposed Regulation and Standard

The proposed regulation and standard were made by referring to regulations, standards and related academic documents related to inspection, evaluation, repair and strengthening, both inside and outside Thailand such as DPT building control acts, DPT standards, manuals for inspection and evaluation of structural performance of reinforced concrete structures of Thailand concrete association, International Existing Building Code (2012), ACI 562: Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings, ASCE/SEI 11: Guideline for Structural Condition Assessment of Existing Buildings, EN 1504: Products and systems for the protection and repair of concrete structures, ACF (2004): Guidelines for maintenance and rehabilitation of concrete structures against chloride induced deterioration. In addition, the proposed standard also takes into consideration the local socio-economic condition in order to suit and be accepted by concerned parties in Thailand.

The proposed standard is divided into 6 parts as follows.

(1) General
(2) Definitions and notations
(3) Overview of inspection, evaluation and maintenance of old and damaged structures and buildings
(4) Inspection of old and damaged structures and buildings
(5) Evaluation of old and damaged structures and buildings
(6) Maintenance of old and damaged structures and buildings

The drafted regulation and standard were circulated to a scholar committee consisting of 5 members, nominated by DPT, to obtain opinions and comments, which was followed by a meeting with the committee together with members of the inspection committee of DPT to obtain details of the opinions and comments. The drafted standard was then revised according to some comments. A technical hearing session on adoption

of the regulation and standard, having 134 participants was also conducted. Most comments were taken into consideration for final revision of the drafts.

9. Impacts on Adopting the Proposed Regulation and Standard

An opinion hearing session, consisting of 134 participants, was conducted on 5 April 2019 at the Sirindhorn International Institute of Technology, Thammasat university to obtain opinions and comments on adopting the proposed regulation and standard. Summary of the opinions and comments as well as the recommended solutions are given as follows.

9.1 Opinions and Comments on Adoption of the Proposed Regulation

Supporting opinions are mainly due to increasing safety for users of the structures, increasing standard of practice, making the practice technically sound as well as practicing in the same right direction.

Three major concerns are budget insufficiency, qualified personnel insufficiency and readiness to enforcement of the regulation.

Regarding problem on budget, most have concern on needs for budget increase which will be burden especially to the government sectors which may have budget constraint. However, this problem may arise at the early state, but proper maintenance will reduce financial burden in long term (lower life cycle cost). This requires understanding of the concerned personnel. Education and training are necessary to provide knowledge to those concerned so that life cycle cost can be estimated based on structural inspection data and proper maintenance program can be implemented.

In regard of personnel, there are still insufficient qualified engineers who have enough skills and experiences or are competent for the overall maintenance works, especially for the inspection and evaluation. This situation does not only exist in Thailand, but also in many parts of the world. This problem is considered more important than the budget problem. Therefore, the following actions are recommended.

1) Arrange training courses, especially on inspection works with practical hours, evaluate the trainees and issue certificate to the trainees whose evaluation results are satisfied. This is to increase the amount of qualified personnel who can work efficiently in this area.
2) Encourage universities to include courses concerning inspection, evaluation, repair and strengthening into their undergraduate curriculums.

Enforcement will not be a problem after the above 2 problems have been solved. However, as the 2 problems may require some time to be solved, a step-by-step enforcement may be one of the interesting selections, for example partial enforcement on some specific categories of structures or buildings or reduce the enforced frequency of inspection and vary the frequency based on significance or age or evaluation results of the structures or buildings, etc.

In conclusion, it is still difficult to enforce the regulation at present. The enforcement of the regulation should be reconsidered or postponed until the problems of insufficient budget and qualified personnel have been more relieved.

9.2 Opinions and Comments on Implementation of the Proposed Standard

Supporting opinions and comments are mainly due to the following reasons.

1) Increase safety for the users of the structures and buildings.
2) Making the maintenance practice technically sound, follow the same standard and direction.
3) Increase service life of the structures, reduce long-term maintenance cost.
4) Enhance capacity of personnel in the field, create new job opportunities and stimulate economy. Two major concerns are budget insufficiency and qualified personnel insufficiency. Comments and suggestions from our research team are the same as those given in section 9.1.

In conclusion, our team would like to recommend that the standard and manuals should be published as soon as possible as they can be used for educating students and

training and preparing engineers for upgrading maintenance related works and enforcement of the regulation in the future.

9.3 Summary for Future Process

In conclusion, we recommend to publish the standard and the manuals but the regulation enforcement should be postponed.

10. Technical Hearing for the Proposed Regulation and Standard

A technical hearing session was conducted to obtain opinions and comments from concerned parties and personnel on the contents of the proposed regulation and standard on 5 April 2019 at the Sirindhorn International Institute of Technology, Thammasat University. The session was participated by 134 persons from academic, public, state enterprise, professional and private organizations.

As for the regulation, there were 76 commenters from 134 participants. Among all comments, 92.1% agree with the regulation while 3.9% disagree and 3.9% had other opinions.

For the standard, 98.7% agree with the standard while 1.3% disagree.

The followings are the essential comments.

(1) Produce safety and raise safety concern to the building owners.
(2) Should establish promotion and supporting measures which are convincible for people to see benefits of having the regulation.
(3) Should consider appropriate frequency of inspection to suit the age or deterioration condition of the structures or buildings.
(4) Should specify suitable criteria for structure inspectors and structural evaluators and establish relevant certifying training programs.
(5) Should launch supporting measures to produce qualified personnel.
(6) Still worry about insufficiency of budget to follow the regulation and standard

11. Manuals for Practice

The following 3 manuals were produced.

1) Manual for Inspection and Evaluation of Structures. The manual was drafted by referring to various standards and guidelines such as Standards for non-destructive tests of reinforced concrete structures (DPT 1501-51 to 1507-51), Report on Nondestructive Test Methods for Evaluation of Concrete in Structures (ACI 228.2R-13) as well as many other related standards and guidelines which are listed as references in the manual.
2) Manual for Repair of Structures. This manual includes the content on materials for repair, revising the existing DPT 1901-51, by making many corrections, referring to Chapter 3 of the ACI 546. Also added are some repair materials that have been used and have potential to be used in the future, but not listed in both DPT 1901-51 ad ACI 546, into the manual such as self-compacting concrete, self-compacting mortar and anti-washout under water concrete.
3) Manual for strengthening of structures which refers to International Concrete Repair Institute (ICRI) Guideline No. 03742.