Structural Engineering Documents

12

Case Studies of Rehabilitation, Repair, Retrofitting, and Strengthening of Structures

International Association for Bridge and Structural Engineering IABSE
Association Internationale des Ponts et Charpentes AIPC
Internationale Vereinigung für Brückenbau und Hochbau IVBH

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Preface

This monograph provides case studies of structural rehabilitation, repair, rehabilitation, strengthening, and upgrading of structures, which might be encompassed - in short - by the convenient umbrella terms “Conservation / Maintenance / Preservation / Upgrading of Existing Structures”. Other umbrella terms for the activities related to maintaining and/or improving the structural performance of existing structures include: Restoration, Structural Renovation, Remedial actions. Rehabilitation and retrofit are sometimes used also as umbrella/generic terms. Terminology is discussed in more detail in the “Introduction”.

The selected studies presented in this IABSE SED (Structural Engineering Document) cover a variety of structural types from different countries. SED 12 has been prepared as a joint activity between two IABSE Working Commissions WC3: *Concrete Structures*, and WC4 (formerly WC8): *Operation, Maintenance and Repair of Structures*.

A large part of existing buildings, bridges and other structures may have a long service life, where they could be subjected to severe environmental and/or operational conditions. These structures represent a strategic heritage of our societies and have an enormous economic value. Due to deficient or absent maintenance, changed operational conditions, new functional requirements, new code provisions, and/or safety necessities, a large number of structures could require to be structurally strengthened, repaired, upgraded, widened, refurbished, re-utilized, or rehabilitated. In most of the cases repair / modification is more convenient than replacement.

Strengthening, rehabilitation, repair, and retrofitting of structures is usually a challenging task because of uncertainties associated with old structures, restrictions on the geometry and materials used, and other structural or functional constraints.

When repairing / upgrading the structural performance of an existing structure, the engineers involved have plenty of possibilities, lots of constraints, and in some cases there are no applicable codes. Strengthening, rehabilitation, repair, and retrofitting is sometimes a complex and exciting work; an art. Restoration, structural renovation, and upgrading of structures is also involving enormous professional responsibility. This monograph is a summary of practices to help structural engineers. The reader will discover different approaches to put forward strengthening or rehabilitation projects. Even identical technical problems could have very different efficient solutions when considering the structural, environmental, and economic factors, as well as contractor and designer experience, materials, etc.

It was the initial intention for this SED to focus on concrete structures, with the hope that a future SED would cover other construction materials. Hence, the papers included in this monograph deal with Concrete Structures only. However, as the SED Editorial Board is planning for continuous addition of new case studies on conservation / upgrading of structures, through an electronic version of documents presented in this monograph, the SED Editorial Board requested that the scope of SED should be widened to cover other construction materials as well. Hence the title of the document was changed: "Concrete Structures" being replaced by "Structures".

The Editors have added four appendices which could provide information that might be of interest to the readers.

The Editors would like to thank the individual authors for their hard work and excellent papers. Special thanks go to the reviewers, Prof. Dr. Daia Zwicky and Mr. Joseph F. Tortorella, for their thorough reviews and useful comments. Thanks also to the Chair and Members of the IABSE SED Editorial Board for their cooperation in preparing the SED, and accepting its idea.

Mourad M. Bakhoum
Juan A. Sobrino

Table of Contents

Chapter

1 Introduction

1.1 Objectives and potential users

This document is intended as a guide for structural engineers and students. The objectives and potential users are outlined in the following:

(1) Many engineers are involved in the design and construction phases in the rehabilitation, repair, retrofit, strengthening, and upgrading of structures. These activities might be encompassed – in short- by one of the convenient umbrella terms: conservation/maintenance/preservation/upgrading of existing structures. A document presenting information, and discussing the different strategies and procedures considered in actual case studies from several countries, on a variety of conservation, preservation, restoration, structural renovation and upgrading projects would be of interest to and appreciated by engineers and students.

(2) Some universities offer courses (senior undergraduate and graduate level) on repair and maintenance of structures. Information presented in this monograph SED 12, should be useful to the students.

(3) Presenting information on repair procedures from different countries in a consistent format (section below) could provide a good example to the students and engineers on organizing the way they approach projects of repair/strengthening, and on writing reports about repair, strengthening, and upgrading of structures.

(4) Some of the repair/strengthening methods, such as external prestressing or glued laminates, although in use for many years, remain among the most commonly applied procedures on many structures; hence information presented in SED12 should be of value.

1.2 Format of the papers in SED 12

The papers in IABSE SED 12 are different from journal or conference papers in two main ways. Firstly, the number of pages of papers in SED 12 could be up to 25 pages, allowing the authors to provide more details than in journals or conference proceedings, where there are usually restrictions on the number of pages. Secondly, the contents of the papers follow a consistent format and organization of sections. This does not mean that it is the only possible format. There could be other formats, even better ones. However, providing a consistent format for all the papers is thought to be of good educational value – in particular for students. The following contents are proposed:

Chapter

2

Upgrading the Seismic Safety of the Chritzi Bridge, Switzerland

Predrag Stefanovic, Structural Engineer, Emch + Berger SA Lausanne, Switzerland

Abstract: In the following text, a method of seismic safety improvement of bridges is proposed. It takes into account following requirements: structural security, serviceability, durability, and resistance towards earthquakes under conditions of the cost and value optimization.

Keywords: seismic safety improvement; elastic response spectrum; structural response.

2.1 Introduction

In the scope of the design methods, particularly of the dynamic loads, the engineer's knowledge and design codes have importantly advanced in the last decades. Most bridges of the Swiss national road system have been constructed before the introduction of the modern Seismic codes. The bridges, which have been built 30 and more years ago in the severe seismic Alpine regions, are to be examined within the maintenance and retrofitting processes. They are also examined for the seismic loads and have to be adjusted to the requirements of the presently valid design codes. This represents a challenging task for the design engineer.

Earthquake is a phenomenon of the rapid ground displacements with a general three-dimensional action vector towards the structure. The structure reacts to the excitation due to earthquakes in two ways: by the transfer and amplification of the ground displacements to its own structural body and by the generation of internal stresses within the structure. This pair of the interactive phenomena, displacements and stresses, is coupled and their relation in the structure is determined by the stiffness of the structural elements. The greater the stiffness of the bearing structure, the smaller are the deformations and the greater are the induced stresses and vice versa. Another problem arises from the spatial nature of the seismic propagation. As a result of wavelike earthquake oscillations, the pier foundations and abutments move asynchronously towards each other. The distance between different bridge supports increases and gets reduced periodically. Moreover, the ground settlement, liquefaction, instability, and collapse can result from an earthquake action.

https://doi.org/10.2749/sed012.009

Chapter

3

Strengthening with Prestressed CFRP Strips of Box Girders on the Chofu Bridge, Japan

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Abstract: Reinforced concrete (RC) box girders of the Chofu Bridge had been strengthened using tensioned carbon fibre reinforced polymer (CFRP) strip method. Before and after the CFRP application, on-site load tests of the bridge were conducted using a 45 t weight vehicle.

Keywords: tensioned CFRP strip; prestress; bending crack; deflection; natural frequency; strengthening.

3.1 Introduction

The Chofu Bridge of Chuo Highway is a three-span continuous reinforced concrete (RC) box girder bridge that was constructed 28 years ago and is located in the western part of Tokyo, Japan. The general view of the bridge is indicated in *Fig. 3.1*. The bridge condition had deteriorated through 28 years of heavy traffic loading and had many cracks on the underside of the main girders.

https://doi.org/10.2749/sed012.021

Chapter

4

Punching Shear Strengthening at the New Station Square in Berne, Switzerland

Dominic Joray, Managing Engineer; **Martin Diggelmann**, Managing Director; Diggelmann + Partner AG, Berne, Switzerland

Abstract: The reinforced concrete slab of the reconstructed Station Square in Berne needed to be strengthened against punching shear. The case study led to the application of a newly developed post-installed punching shear reinforcement with inclined bonded bars.

Keywords: post-installed punching shear reinforcement; conservation; strengthening; inclined bonded bars; brittle failure; deformation capacity; construction process.

4.1 Introduction

The Station Square in Berne, Switzerland, as it is shown in *Fig. 4.1*, was constructed from 1971 to 1973 and reorganized and rehabilitated in 2007. The main element is an underground passage and shopping centre with an area of 7500 m^2. The ceiling is a 600 mm thick reinforced concrete slab that is mainly supported by steel columns. In front of the station building, a major city road, various tramways, and bus lines cross the square. The underground passage is about 134 m long and 42–61 m wide with a 54 m long and 16 m wide addition to the west. The clearance height is approximately 3.50 m. Several stairways and elevators around the perimeter give access to the underground passage.

There are 81 columns in total, usually in a grid of 8.44 m $\times$ 9.00 m. The columns are mainly steel pipes with an outer diameter of 368 mm and a thickness of 35 mm. Some columns consist of other steel profiles or cast-in-place reinforced concrete. The outer edge of the concrete slab is supported by reinforced concrete walls with neoprene bearings. The whole slab is divided into five elements. The initial design is based on the former Swiss codes SIA 160 (1970) [1] and SIA 162 (1968) [2]. The load model for traffic consisted of two axle loads of approximately 200 kN each and an accompanying load of approximately 5 kN/m^2 including a dynamic factor. The total dead load of road bed and pavement is about 30 kN/m^2.

https://doi.org/10.2749/sed012.0035

Chapter

5

Strengthening of the Frame Structure at the Timisoreana Brewery, Romania

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Abstract: Many structures built in Romania before 1970 were designed for gravity loads with inadequate lateral load resistance because earlier codes specified lower levels of seismic loads. Some of these structures are still in service beyond their design life. Also, some deterioration was observed in existing structures due to the actions of different hazard factors. This paper presents the case study of a brewery with reinforced concrete framed structure of five storeys and a tower of nine storeys, which has been assessed and strengthened. The brewery and the tower were built in 1961 and an extension in 1971. An assessment performed in 1999 showed up local damages at slabs, main girders, secondary beams, and columns; concrete carbonation; concrete cover spalled over a large surface; complete corrosion of many stirrups and deep corrosion of main reinforcement; and some broken reinforcement. Such damage was caused by salt solution, CO_2, relative humidity RH $\approx$ 80%, and temperatures over 40°C. Also, inadequate longitudinal reinforcement was deduced from the structural analysis. The initial design, done in 1960, was according to the Romanian codes of that time with provisions at low seismic actions. The structural system weakness is due to present-day high seismic actions. The rehabilitation of the reinforced concrete structure was performed by jacketing with reinforced concrete for the main and secondary beams and columns. In 2003, due to continuous operation and subsequent damage of the structure, a new assessment was required. It was found that some beams and one column were characterized by inadequate main and shear reinforcement as well as corrosion of many stirrups at beams. The strengthening solution adopted was based on carbon fibre reinforced polymer composites for beams and column.

Keywords: existing reinforced concrete structures; reinforcement corrosion; seismic action; assessment and rehabilitation; structural analysis; strengthening solutions.

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Chapter

6

Strengthening and Rehabilitation of a Heating Plant Chimney, in Poland

Andrzej B. Ajdukiewicz, Prof., Dr; **Jacek S. Hulimka**, Assist. Prof., Dr
Silesian University of Technology, Gliwice, Poland

Abstract: A case study of reinforced concrete chimney repair, strengthening, and finally general modernization is described. The specific local conditions and the changeable decisions of the user caused the application of three different approaches to the reconstruction works.

Keywords: concrete destruction; construction faults; repair methods; reinforced concrete chimney; modernization processes; advanced strengthening methods.

6.1 Introduction

This paper describes a case study of a reinforced concrete (RC) chimney structure, over 80 m high, which has been repaired and reconstructed in a series of actions, particularly in three distinct stages.

The history of the RC chimney in the town heating plant goes back to 1976 when it was erected. From the beginning it had several defects. The chimney is situated in a seaside resort and serves as the only heating plant in the vicinity. The heating plant is responsible for heat and hot water supplies for the town of 45 000 people. The town includes a big spa district.

The chimney was designed and erected as a cylindrical shaped, RC structure of 80.5 m height. The outer diameter was 4.16 m and the inner diameter was 3.20 m. The total thickness of the wall consisted of a RC wall of the chimney carrying shaft 0.22 m thick, a heat insulation layer 0.12 m made of granulated slag, and a constructional reinforced wall of an exhaust gas conduit made of refractory concrete 0.14 m in thickness (*Fig. 6.1*). Both walls were erected simultaneously in double slip-shuttering. This detail influenced the quality of construction. The time of concrete setting in both shells was of particular importance. The contractor of the structure adjusted the speed of the boarding slide to the setting conditions of the refractory concrete in the inner shell. As a result, the concrete in the outer carrying shell showed numerous defects.

https://doi.org/10.2749/sed012.081

Chapter

7

Rehabilitation of the Kumho Group Seoul Headquarters, Korea

Geonho Hong, Professor, Department of Architectural Engineering, Hoseo University, Asan, Chungcheongnam-do, Korea; **Youngsoo Chung**, Professor, Department of Civil Engineering, Chung-Ang University, Seoul; Anseong, Korea and **Hyekyo Chung**, CEO, DnK Construction Inc., Seoul, Korea

Abstract: This paper is a case study of an office building rehabilitation in Seoul, Korea. The partly built building, originally designed as a general office building, contained 20 stories above and seven below ground. After the first floor slab was constructed, construction was stopped because of financial difficulties of the previous owner. The new owner revised the architectural plan, design, and height of the building with 29 stories above and eight below ground. Because of the long-term stop of the construction and change of the architectural design, large-scale repair and rehabilitation work was carried out in 2006.

Keywords: rehabilitation; repair; office building; case study; demolition; extension.

7.1 Introduction

The owner of this building is a fully accredited and prosperous company involved in several business fields in Korea and worldwide. The company needed a new building for its second headquarters for their expanded personnel and department. After considering several buildings and locations, the company purchased this building in Chungro-Gu, Seoul.

The building, originally designed as a general office building, contained 20 stories above and seven below ground. After the basements and the first floor slab were constructed, construction was stopped in 1993 because of the financial difficulties (*Fig. 7.1*).

After purchasing the building, the owner revised the architectural plan, design, and height of the building to be 29 stories above and eight below ground (*Fig. 7.2*). Because of the long-term stop of the construction and change of the architectural design, the architectural drawings, construction documents, and site inspection reports had to be reviewed. The owner hired a structural engineering company to conduct an extensive field investigation, repair, and

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Chapter

8

Strengthening the Murhasaari Bridge with External Prestressing, Finland

Ilkka Vilonen, L.Sc., Ramboll Finland Ltd, Tampere, Finland

Abstract: The Murhasaari Bridge is located on Highway 11 between Pori and Tampere, which is one of the most heavy traffic roads in the Finnish road network, carrying total loads exceeding 140 t. The bridge crosses a lake near Nokia with three spans 26 + 52 + 26 m. The deck width is 10.5 m from railing to railing.

The bridge piers have direct foundations on solid moraine strata, and there are no signs of movements in the substructure. The bridge superstructure is a continuous box girder, made of reinforced concrete without prestressing. The cross section has three cells in the side spans, changing to two cells in the main span.

The bridge was constructed in 1962, when the design traffic load was only 140 kN axle load and distributed load 4 kN/m^2. These loads are much smaller than the loads used today.

Soon after construction, routine inspection detected deflections of the midspan, which also impaired proper functioning of the expansion joints at the abutments. Repair in 1977 included replacement of the moisture isolation and asphalt on the bridge deck, injection of some cracks with epoxy, and repair of expansion joints and edge beams.

Between 1976 and 1994, the midspan deflection increased by 110 mm, and in the following years, special inspection and load testing disclosed extensive cracking and insufficient load-carrying capacity.

The bridge was strengthened in 1999 with post-tensioning using external cables, placed inside the box chambers. At both ends of the deck, new cross beams were constructed to anchor the post-tensioning cables. The original cross beams along the bridge were used as deviators, to get suitable bending moments and shear forces opposite to the original ones. As a result, the midspan deflection was reduced by 50 mm, the growth stopped, and the need for frequent repair of the expansion joints eliminated.

Strengthening the bridge with post-tensioned external cables was found to be a very effective way to increase the bearing capacity. Bridges requiring this kind of rehabilitation are usually

Appendix

A

List of Articles from IABSE—SEI Journal Related to Topics of IABSE SED 12

This Appendix mainly includes a list of articles published in IABSE SEI Journal, which are related to topics of SED 12 (rehabilitation, repair, retrofit, strengthening, upgrading, . . . of structures). The listed articles could present additional case studies to those presented in SED 12. The appendix also includes information on where to order other IABSE publications related to the topics of SED 12 (e.g. IABSE Conference Proceedings, and other SEDs). Additional case studies relevant of the topics of SED 12 could be found also in the followings:

(I) Articles from IABSE SEI Journal: from 1991 to 2009. To obtain a copy of the articles refer to the website of IABSE SEI: http://www.ingentaconnect.com/content/iabse/sei

(II) IABSE Conferences: http://www.iabse.org/publications/iabsereports/index.php

(III) IABSE SED: http://www.iabse.org/publications/onlineshop/index.php

(IV) IABSE E-Learning: (Audio Visual presentations), Refer to: http://www.iabse.org/

(I) Articles from IABSE SEI Journal

The articles from IABSE SEI Journal on topics relevant to SED 12 are organized in groups as follows. The groups/categories should be considered as tentative. There are no definite limits or rigid boundaries between the activities in the groups, and there is lots of interaction. The groups are not necessarily organized in chronological order.

Note: In the following, the numbers in parentheses[(1)–(41)] refer to the relevant parts in the list of articles. For definitions (partial list), please refer to "*Introduction*", section on *Terminology*, and to Appendix B (section X).

Group (A): Maintenance[(1)] (Policy, Strategy, Optimization, Cost), Management systems[(2)] (Bridges, Building, Facilities), Operation[(3)]. This group is related mainly to the policies and planning of the activities in the post-construction phase, aiming at maintaining and/or improving structural performance.

Group (B): Inspection[(4)], Monitoring[(5)], Testing[(6)] and Load Tests, Non-destructive Testing. This group is related mainly to observations and investigations carried out on the structures.

Group (C): Assessment[(7)], Evaluation[(8)], Extending Service Life[(9)], Load Capacity[(10)], Performance[(11)], Robustness[(12)], Safety[(13)]. Additional relevant keywords also include: Analysis, Appraisal, Bridge Sufficiency, Durability, Investigation, Rating, ... This group is related mainly to condition assessment and evaluation of structural performance.

Appendix

B

List of Some Codes, Guidelines, Manuals, Documents, and Books on Assessment, Conservation, Evaluation, Inspection, Maintenance, Preservation, Rehabilitation, Repair, Retrofit, Strengthening and Upgrading Structural Performance

This Appendix includes a list of references on topics related to topics of SED 12: Repair, Rehabilitation, Retrofitting, Strengthening, Upgrading, . . . of Structures. The list of references in this Appendix is organized into the following sections: (I) Codes, Guidelines, Manuals, and Standards; (II) Books; (III) Documents, Bulletins, Reports, and Special publications published by International Associations Organizations; (V) Journals; (IV) Symposium, Workshop and Conferences; (VI) References on Historical and Heritage Structures; (VII) Videos and Presentations; (VIII) Relevant Websites and Relevant References; (IX) Checklists; (X) Terminology. For list of references on Diagnostic Crack Patterns and Causes of Deterioration in concrete structures, please refer to Appendix C in this document.

This list includes more than 600 references related to topics of SED 12. It is not a full or a complete list; however, it might be considered a wide-ranging list. The list is based on many searches on the Internet, however many other excellent references could be available which are not listed here.
(Note: Journal papers and Conference papers are not included in the lists in Appendix B.)

NOTE: Website links mentioned in this Appendix are active in January 2010. Website links might change without notice.

(I) Codes, Guidelines, Manuals, Standards (Partial List):

1. AASHTO CORE-1-M Guide for Commonly Recognized Structural Elements with 2002 and 2010 Interim Revisions, American Association of State Highway and Transportation Officials, Washington, D.C., USA.
2. AASHTO FIM-2-UL – Foundation Investigation Manual, 2nd Ed., USA, 1978.
3. AASHTO GBMS-1 – Guidelines for Bridge Management Systems, 1st Ed., USA, 1993.
4. AASHTO GMPC-2 – A Guide for Methods and Procedures in Contract Maintenance, 2nd Ed., 2002.
5. AASHTO IGSRB-1 – Inspectors' Guide for Shotcrete Repair of Bridges, USA, 1999.
6. AASHTO MBE-1-M – Manual for Bridge Evaluation, 1st Ed., with 2010 Interim Revisions, USA, 2008.

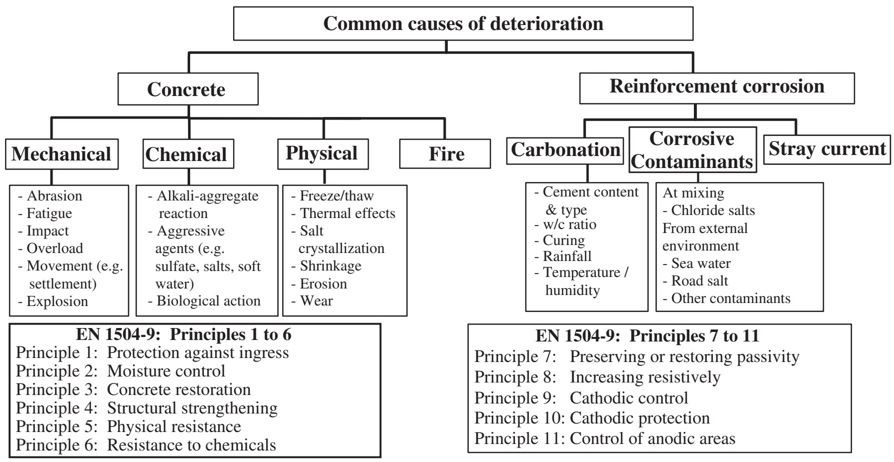
Appendix

C

Examples of Diagnostics of Crack Patterns and Causes of Deterioration in Concrete Structures

This Appendix includes examples of diagnostics crack patterns, deterioration patterns, and causes of deterioration in concrete structures.

Appendix C-1: Common causes of defects and general principles in EN 1504-9.
Appendix C-2: Diagnostic chart on symptoms and causes of cracking.
Appendix C-3a: A typical crack pattern of a portal frame pier with overhangs.
Appendix C-3b: A typical crack pattern of an abutment.
Appendix C-4: Schematic figure for material deterioration and performance degradation.
Appendix C-5a: Examples of cracking in reinforced concrete bridge deck slabs.
Appendix C-5b: Examples of cracking in reinforced concrete bridge beams.
Appendix C-5c: Examples of cracking in box girder bridges.
Appendix C-6: Common types of cracks and approximate time of appearance.
Appendix C-7: Examples of cracking in box girder bridges.



Refer also to Appendix D in this document

Appendix C-1: Common Causes of Defects and General Principles in EN 1504-9.
(Based on: EN 1504-9: Products and systems for the protection and repair of concrete structures. Principles for the use of products and systems, Figure 1)

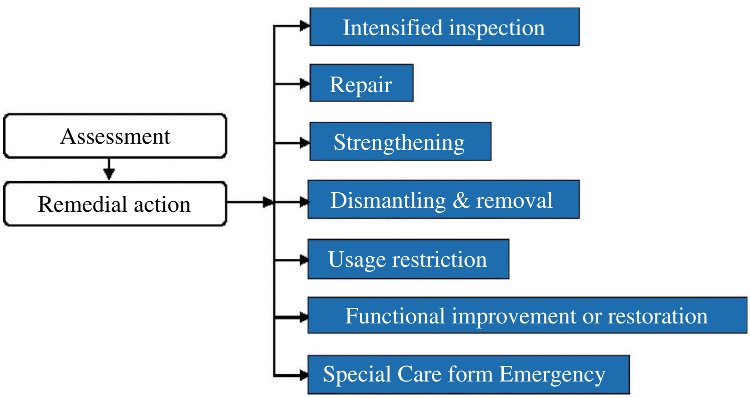
Appendix

D

Guidelines on Selection of Rehabilitation, Repair, Retrofit, Strengthening and Upgrading Methods

This Appendix includes examples of guidelines on selection of repair methods:

Appendix D-1: Types of remedial action.
Appendix D-2: Stages and activities during entire life of railway bridges.
Appendix D-3: Example of decision tree for repair of bridges.
Appendix D-4: Additional examples of figures, flowcharts, and tables selection of methods of repair/rehabilitation/retrofit.
Appendix D-5: Relationship between performance verification indices and retrofitting methods (a & b).
Appendix D-6a: Contents and structure of the new EN 1504.
Appendix D-6b: Phases of typical repair projects.
Appendix D-6c: Principles and methods for protection and repair of concrete structures.
Appendix D-7: Global quality index to determine the rehabilitation decision.
Appendix D-8: Decisions for structural intervention for retrofitting of building.



Appendix D-1: Types of remedial action
(From: Concept of Maintenance Part in the JSCE Standard Specifications for Concrete Structures & Its Future Strategy, by Koji Takewaka & Toyoaki Miyagawa, IABSE – fib Conference: Codes in Structural Engineering, Developments & Needs for International Practice, Croatia, May 3–5, 2010, Figure 5)

Structural Engineering Documents

Objective:

To provide in-depth information to practicing stuctural engineers in reports of high scientific and technical standards on a wide range of structural engineering topics.

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Topics:

The International Association for Bridge and Structural Engineering (IABSE) operates on a worldwide basis, with interests of all type of structures, in all materials. Its members represent structural engineers, employed in design, academe, construction, regulation and renewal. IABSE organises conferences and publishes the quarterly journal *Structural Engineering International (SEI),* as well as reports and monographs, including the SED series, and presents annual awards for achievements in structural engineering. With a membership of some 4,000 individuals in more than 100 countries, IABSE is *the* international organisation for structural engineering.

Readership:

Practicing structural engineers, teachers, researchers and students at a university level, as well as representatives of owners, operators and builders.

Publisher:

The International Association for Bridge and Structural Engineering (IABSE) was founded as a non-profit scientific association in 1929. Today it has more than 3900 members in over 90 countries. IABSE's mission is to promote the exchange of knowledge and to advance the practice of structural engineering worldwide. IABSE organizes conferences and publishes the quarterly journal Structural Engineering International, as well as conference reports and other monographs, including the SED series. IABSE also presents annual awards for achievements in structural engineering.

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The book is a summary of practices to help structural engineers. The reader of this book will discover different approaches to put forward strengthening or rehabilitation projects. Even identical technical problems could have very different efficient solutions, as discussed in the papers, considering structural, environmental, economic factors, as well as contractor and designer experience, materials, etc.

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