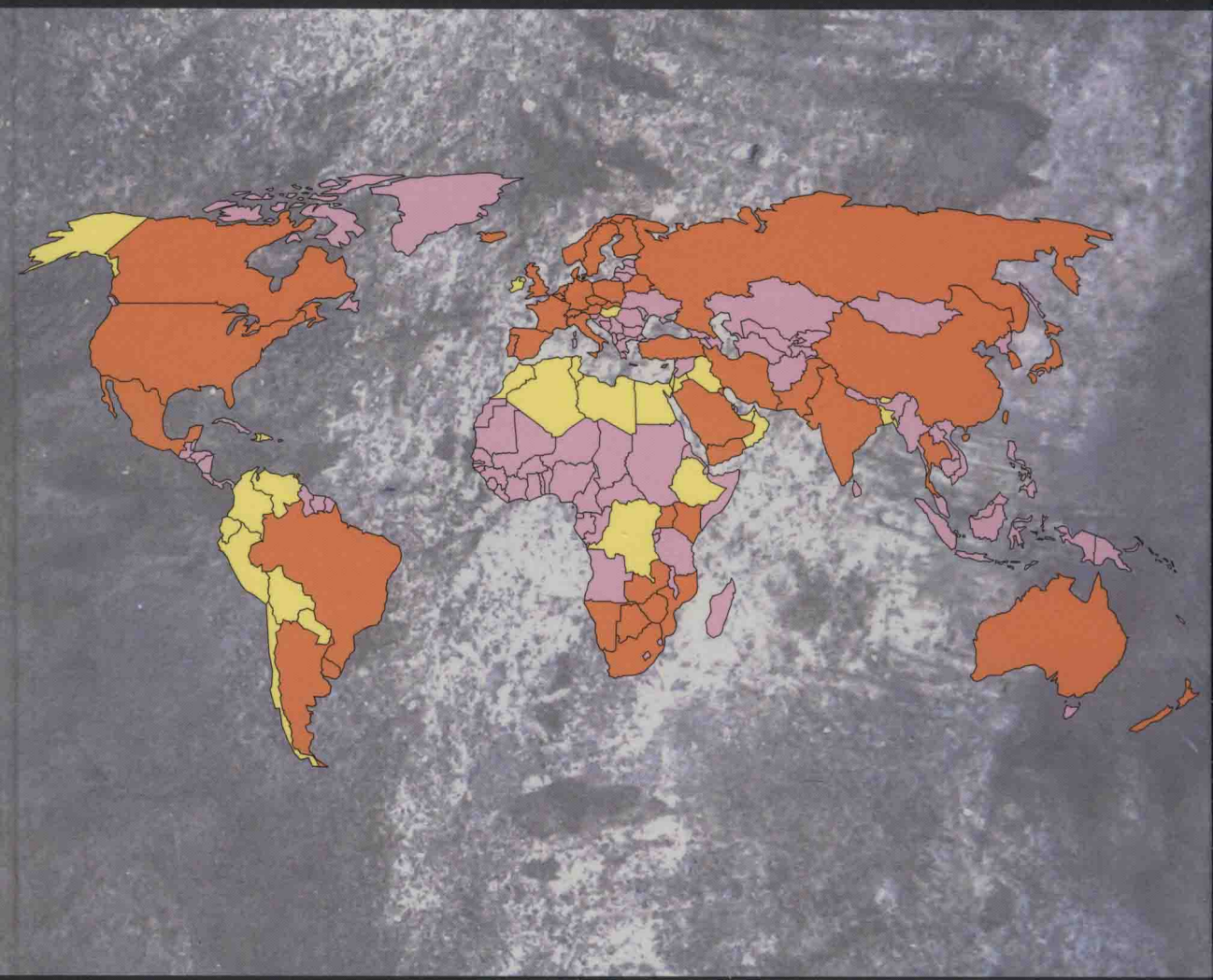
Alkali-Aggregate Reaction in Concrete

A World Review



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CRC Press
Taylor & Francis Group
A BALKEMA BOOK

Alkali-Aggregate Reaction in Concrete: A World Review

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CRC Press
Taylor & Francis Group
Boca Raton London New York Leiden

CRC Press is an imprint of the
Taylor & Francis Group, an **Informa** business

A BALKEMA BOOK

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by Integra Software Services Private Ltd

Printed and bound in Great Britain by Antony Rowe (A CPI-group Company), Chippenham, Wiltshire

Library of Congress Cataloging-in-Publication Data

Applied for

Published by: CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

ISBN: 978-1-138-02756-5 (Hardback)
ISBN: 978-1-315-70895-9 (eBook)

Alkali-Aggregate Reaction in Concrete: A World Review

Preface

In 1992 a new and ground breaking attempt to provide a worldwide review focussing on the problem and implications of alkali-silica reaction (ASR) in concrete structures was published as a collection of contributions from internationally recognised materials experts. These contributions were brought together by the editor, Professor Narayan Swamy, in a single volume. This book, *The Alkali-Silica Reaction in Concrete*, was published by Blackie and Sons in the UK and Van Nostrand Reinhold in America. It provided the civil engineer, materials scientist and other professionals concerned with concrete structures with a unique review of this relatively rare but very costly cause of concrete deterioration that had been identified in a number of countries round the world.

This first review explained the nature of the mechanisms of alkali-silica reaction, which is entirely different from other causes of premature concrete degradation. The review gave first insights into the various international approaches relating to the diagnosis, evaluation and avoidance of this type of deterioration caused by the reaction. Although the countries providing information in this first compilation included the UK, Denmark, Iceland, Canada, New Zealand, Japan and India, it is apparent that many parts of the world remained absent from this list, including the USA where the problem had first been identified.

The contributions in the 1992 edition clearly demonstrated that laboratory research studies alone are inadequate to describe the complex behaviour of this reaction in real concrete structures. The conditions and effects of the deterioration that develop appeared to be different in apparently unpredictable ways in different regions of the world. It came to be realised that factors additional to the materials used in the production of concrete will have an influence on the initiation, progression and on the deleterious effects resulting from the reaction between aggregate and alkalis in the cement. These included variations in atmospheric humidity, temperature fluctuation and ranges, freeze-thaw cycles and rainfall. Consequently, in order to investigate the effect of the reaction on a particular concrete structure fully, all these factors needed to be evaluated. This is not to say that laboratory research studies are irrelevant, it is rather that a combination of both laboratory and field investigation of concrete structures is essential to a proper understanding of the problems caused by the alkali-aggregate reaction.

In the 25 years since 1992 considerable progress has been made in understanding the problem of alkali-aggregate reaction in concrete and how best to avoid or mitigate the premature concrete degradation that it causes. This increase in knowledge has come

about in part through intensive research efforts both in the laboratory and on field concrete. Also, there has been a gradual realisation that some concrete structures in many more countries round the world than was first realised are susceptible to this type of decay mechanism, with its serious consequence for important structures such as dams and bridges. This research has been a truly international collaboration with research studies undertaken in many different countries and shared globally through a series of regular international conferences since 1974. The studies have focussed on several different areas, including better understanding of the mechanisms of the reaction, the most effective means of avoiding the use of materials in concrete that are susceptible to initiating the reaction, and options for mitigating or repairing concrete structures that have become damaged by alkali-aggregate reaction.

This current book, like its 1992 predecessor, is a compilation of contributions from many international experts that have been edited into a single volume to provide a state of the art review of the problem of alkali-aggregate reaction as it affects concrete structures in countries around the world. It provides an up to date appraisal of the research conclusions that have been reached and the progress made in understanding the causes and effects of alkali-aggregate reaction in concrete, both at a laboratory research level, as a construction material and in the concrete structures themselves.

A large number of countries world-wide now realise that the alkali-aggregate reaction in concrete is a real and costly problem that may affect their own concrete structures. Many of these countries have assessed the particular aggregate materials and the concrete mix designs they use and have developed their own national test methods for the diagnosis and evaluation of the reaction. A number of these have introduced national standard specifications for concrete, aimed at avoiding susceptible materials and mix designs in new concrete structures.

This book is unique in that it provides not only a review of the current state of research findings relating to the understanding of the reaction and its effects, but also an up to date summary of current national test procedures and specifications that have been adopted in countries round the world. It also provides illustrative case study investigations of alkali-aggregate reaction in concrete structures encountered in these countries. It has already been noted that many countries and regions were missing from the book published in 1992; this new edition has attempted to address and update this incomplete coverage. As can be seen from the table of contents, most regions and countries round the world are represented in the various chapters so that an almost complete global coverage of the reaction and its effects on concrete structures is now available.

The first five chapters of this book attempt to pull together and synthesise current laboratory and field research findings in the principal areas of importance to the understanding of the mechanisms, causes and effects of the alkali-aggregate reaction in concrete and related materials. Chapter 1 is concerned with the chemistry and mechanisms underlying the reaction including the controversial explanations of the effect relating to the sometimes observed variable expansions of the concrete that results from the reaction and referred to as 'the pessimum proportion' effect. The second chapter provides a generalised review and a systematic approach to estimating risk of alkali-aggregate reaction and the measures required to minimise or eliminate its initiation and expansive effects. It also examines the range of tests and specifications for diagnosis and avoidance of the reaction in current use globally.

The possibility of an expansive reaction involving alkaline concrete pore fluids and impure carbonate aggregates is discussed in detail in Chapter 3. Although the development of de-dolomitisation reaction rims around dolomitic carbonate aggregate particles in a concrete is well documented, it has been unclear as to whether the rare examples of expansion of concretes containing these aggregates is due to variants of an alkali-carbonate reaction, or the result of a cryptic alkali-silica reaction arising from siliceous components in the carbonate aggregate. The evidence and research relating to this matter is examined fully in Chapter 3 which presents the latest findings and conclusions concerning this issue.

Chapter 4 deals with the various methods that are in current use as methods of avoiding, or preventing alkali-aggregate reaction in concrete. It provides an overview of the generally accepted approaches to this problem assembled from all the available expertise and experience that has been gathered from countries worldwide. Chapter 5 follows this, with a detailed global appraisal of methods currently available for diagnosing the reaction in an existing concrete structure and an overview of the repair and management options available for dealing with concrete structures that are affected by expansions caused by reaction of this kind.

The remaining chapters from 6 to 16 review and discuss in detail the particular problems of alkali-aggregate reaction in concrete as experienced by countries round the world. The materials and mechanisms of the reaction affected by the particular factors present in the country or region are presented together with the counter measures and testing regimes they adopt. Case histories are presented to provide practical illustrations of the investigations and the measures used to avoid or mitigate the problem of premature deterioration of concrete structures, due to the reaction, that are currently in use in these countries.

In a few countries there is no information available concerning alkali-reactivity in concrete structures. In a number of others, although the civil engineering organisations are aware of the possibility of alkali-silica reactivity in concrete and have test methods and specifications in place to avoid the use of potentially reactive materials in their concrete, no data relating to case histories have been published. This may reflect the validity of the preventative measures they have put in place, alternatively the expansive reaction may not have been correctly identified in structures, or the details of relevant investigations have not been published.

The countries and regions reviewed in these last eleven chapters are: the UK & Ireland, Nordic Europe, Mainland Europe, Turkey & Cyprus, the Russian Federation and neighbouring Asian Countries, North America, South and Central America, Southern and Central Africa, Japan, China and South-East Asia, Australia and New Zealand, the Indian Sub-Continent and the Middle East and North Africa. Between them they cover almost all the developed and developing world and thus represent the first full global review of instances of alkali-aggregate reaction in concrete.

It has been said that editing a book of chapters written by various authors is like trying to herd cats and we understand the feeling, but this book only exists because of the generosity of our many gifted friends and colleagues, who have selflessly and patiently donated their time and expertise to the cause. We are really very, very grateful and hope that they will be proud of the outcome and can forgive us in due course. They are all recognised in the Contributors & Acknowledgements sections.

This current up to date review with its many expert contributions has been generated from a basis of knowledge and wisdom built up over many years by the expertise of scientists such as Thomas Stanton, who introduced the world to the uncomfortable reality of AAR in 1940. There are of course many other internationally acclaimed engineers and scientists who have since influenced our understanding of AAR and our strategies for minimising its risk and managing affected structures. Amongst the many, perhaps we might mention Gunnar Idorn, who brought AAR awareness to Europe, developed the role of petrography in its study and launched the on-going series of International Conferences on AAR (the ICAARs), which have facilitated the global dissemination of knowledge about AAR and solutions for its control.

Finally, we are indebted to Emeritus Professor R Narayan Swamy for arranging publication of the first (1992) edition of this book and for so encouraging and supporting us to achieve this new edition; it is only to be hoped that the updated and greatly enlarged volume is a worthy successor.

Ian Sims & Alan Poole
February 2017

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Dr Ian Sims is a Director of RSK Environment Ltd in the UK, where he is responsible for Materials Consultancy and Expert Witness Services. He graduated in geology at Queen Mary College (London University) in 1972 and then undertook doctoral research in concrete technology, including AAR in the British Isles, and his PhD was awarded in 1977. Ian joined Sandberg LLP in London in 1975 and gained wide experience with construction geomaterials. In 1996, he moved to STATS Limited, which joined RSK Group PLC in 2008. He has specialised for over 40 years in concrete, its constituents and all aspects of AAR. Between 1988 and 2014, Ian was Secretary of the RILEM Technical Committees on AAR, when he was awarded RILEM Fellowship. As a Fellow of the Geological Society, he was Secretary for four sequential Engineering Group working parties, producing report-books on

Aggregates, Stone and Clay materials and construction in Hot Deserts, also being an editor for the current edition of Aggregates and for Clays; Ian received the Society's Engineering Group Award and later the Coke Medal. He has served on many other committees, including chairing the editorial panel for ICE's journal 'Construction Materials' and currently chairing the British Standards committee on Aggregates. Ian's publications include 'Concrete Petrography: a handbook of investigative techniques', now in its second edition.

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Dr Alan Poole followed an academic research and teaching career in the University of London until 2000, as senior lecturer, the director of the Geomaterials Masters course and as supervisor to over 20 PhD students. His research interests were principally concerned with the petrology of civil engineering materials and in the last 30 years he specialised in problems associated with concrete and related materials. He became an acknowledged expert in all aspects of alkali-aggregate reaction in concrete. This expertise has led to his appointment as a consultant to numerous governmental and major civil engineering organisations worldwide. He has been actively involved with the series of International Conferences into Alkali-Aggregate Reaction in Concrete (ICAARs) as UK representative on its International Organising Committee until 2004. He chaired the two UK ICAAR conferences (1976 and 1992) and has contributed numerous papers on AAR to these conferences. His researches, consultancy investigations and association with international experts at conferences has led to his authorship of chapters in a number of technical books on constructional materials, over 120 scientific papers and co-authorship of 'Concrete Petrography' (2016), which deals with all aspects of the investigation of concrete. He is secretary to the Geological Society Engineering Group's 'Applied Petrography Group' (APG) and is also a member of British Standards Institution committees concerned with concretes and aggregates.

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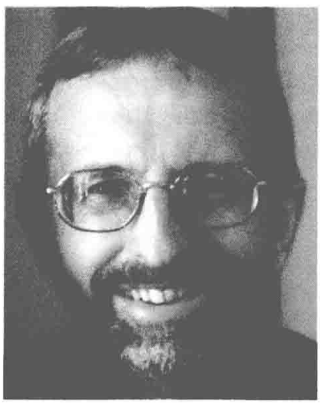

Dr Mark G Alexander is Emeritus Professor of Civil Engineering in the University of Cape Town, and a Member of the Concrete Materials and Structural Integrity Research Unit at UCT. He has a PhD from the University of the Witwatersrand, Johannesburg, and is a Fellow of the South African Institution of Civil Engineering, the South African Academy of Engineering, RILEM, and the University of Cape Town. He is a registered Professional Engineer in South Africa. He teaches and researches in cement and concrete materials engineering relating to design and construction, with interests in concrete durability, service life prediction, concrete sustainability, and repair and rehabilitation of deteriorated concrete structures. He is active in international scientific circles and publishes in local and international journals. He is Immediate Past President of RILEM. He acts as a specialist consultant on concrete materials problems. He has co-authored 'Aggregates in Concrete' (2005) and 'Alkali-Aggregate Reaction and Structural Damage to Concrete' (2011), and edited a new book 'Marine Concrete Structures – Design, Durability and Performance' (2016).

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Dr Özge Andiç-Çakır is currently Associate Professor in the Civil Engineering Department at Ege University in Izmir, Turkey, with a PhD in materials of construction. She has been the supervisor of many national projects in the field of building materials and sustainable materials technologies for eight years. Her research interests are functional concrete design and technology, aggregates, bio-inspired materials, energy efficient and sustainable building materials. Özge supervises the Imaging and Microstructural Analysis Laboratory at Ege. She has participated in several national and international projects, publishing more than 70 scientific papers. She also has experience in technology transfer, organization and development of dissemination activities like conferences, seminars and workshops.

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Dr Karin Appelquist has been working at the Swedish Cement and Concrete Research Institute (CBI) since 2010. She has a PhD from Gothenburg University in Mineralogy and Petrology (2010). Her main activities at CBI are aggregate and concrete petrography and she is responsible for ASR expansion methods in Borås. She is also a member of RILEM TC 258-AAA (2014–2019).

Geoff Blight
(sadly deceased)

The late Professor Geoffrey E. Blight obtained his BSc Degree in Civil Engineering from the University of the Witwatersrand (Wits) in 1955, and an MSc (Eng) degree from Wits in 1958. In 1961, he obtained his PhD at Imperial College, London, for work on soil mechanics, and then, in 1975, a DSc(Eng) from London University for work on geotechnical engineering. This was followed by a DSc(Eng) from Wits University in 1985 for innovative work in materials engineering. In 1993, he was awarded a DSc(Eng) from the University of Cape Town for his work on developing design information from *in situ* tests. Wits University awarded him a D.Eng in 2001 for the contribution of his research work in developing and changing civil engineering practice.

Geoff was Professor of Civil Engineering at Wits University from 1969 until his retirement in 2002. From then until his death in 2013, he was an Honorary Professorial Research Fellow in the School of Civil and Environmental Engineering at Wits, and he continued to undertake research and supervision of postgraduate students. Among numerous achievements, his work stands out for contributions in the fields of soil mechanics and geotechnical engineering, and on the structural stability of concrete deteriorated by alkali-silica reaction, both of which represent unique contributions to these fields of study internationally.

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Dr Mario R de Rooij is a Senior Project Manager at TNO in Delft, The Netherlands. He received his training as a materials scientist and engineer at Delft University of Technology. After his Masters (1994) in the field of inorganic chemistry, he specialized in cement chemistry and microscopy during a PhD in Civil Engineering, also at Delft University of Technology (2000) and a Post-Doc period at Northwestern University (2000), Illinois, USA. He continued his career in the field of concrete durability working for TNO in the Buildings Materials Group, focusing on the remaining service life of existing concrete structures. For a period of six years (2002–2008) he was part-time Assistant Professor at Delft University of Technology, teaching microstructure development of cement-based materials and microscopy. It was during this time that he initiated the RILEM Concrete Microscopy Course in Delft for PhD level students. Returning full-time to TNO in 2008, his interest shifted to re-use and adding value to secondary materials for building materials purposes, including alkali-activated materials.

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Dr Eduardo M. R. Fairbairn is a Professor in Civil and Environmental Engineering at the Federal University of Rio de Janeiro, Brazil. He has a PhD in Mechanics applied to Constructions from the Université de Paris VI in France. On sabbatical leave, he worked as a researcher at Laboratoire Central de Ponts et Chaussées (now IFSTTAR) and held a senior internship at Arizona State University in the area of nanotechnology. His main interests are in numerical modelling and experimental analysis of concrete structures, from oil well slurries to massive concrete and sustainable cementitious materials. He is currently the chairman of the RILEM technical committee TC-254 'Thermal Cracking of Massive Concrete Structures'. Prof. Fairbairn has served as a consultant for government agencies and private corporations in the fields of electrical energy generation and the oil and gas industry. He has coordinated several projects for numerical modelling and experimental analysis of alkali-aggregate reaction (AAR) and has also supervised several PhD and MSc theses in the use of fibres and pozzolanic materials for AAR mitigation.

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after A.A. Gvozdev (NIIZhB), and Professor at the Moscow State University of Civil Engineering (MSUCE) – State National Research University. He is a full member of the Russian Engineering Academy and International Academy of Engineering (IAE). Vyatcheslav is the Russian Federation Government Prize winner in the field of science and technology, The Honorary Builder of Russia and The Engineering Merit Award winner. Member of DAC in RILEM, the Regional Convener of the RILEM in East Europe and Central Asia. He is a RILEM Fellow, also a Member of ACI and Member of ACI Technical committees on material science and nanotechnologies in concrete, and Head of Russian National delegation in fib. Vyatcheslav is Vice-President of IAE, Russtandard representative in ISO committees, and First Vice-President of the Russian Structural Concrete Association. He has authored more than 350 research papers and 70 patents. Research interests include chemical admixtures for concrete and mortars, special binders and concrete, problems of concrete durability, nanotechnologies in construction, and sustainable development.

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Dr Isabel Fernandes holds an MSc degree in Engineering Geology and a PhD in Geology of Alkali-Silica Reaction (ASR) and the evaluation of aggregates for concrete. Currently, Isabel is Assistant Professor at the University of Lisbon in Portugal, teaching courses of Engineering Geology and Rock Mechanics. She is co-author of 3 books, 10 book chapters, and about 100 papers published in scientific journals and international conferences. In addition to her lecturing duties, she supervises a number of MSc and PhD students with theses covering different topics of engineering geology including the evaluation of aggregates for concrete. As a member of RILEM Technical Committee 219-ACS from 2008 to 2014, Dr Fernandes was a leading participant in compilation of the recommendation '*AAR-1.1, Detection of Potential Alkali-Reactivity – Part 1: Petrographic Examination Method*', included in the 2016 book '*RILEM Recommendations for the Prevention of Damage by Alkali-Aggregate Reactions in New Concrete Structures*'. She was author and editor of the companion volume,

'*Recommended Guidance AAR-1.2, Petrographic Atlas*'. This book, published in 2016, presents the main reactive aggregates used worldwide for which 70 samples were collated from 25 countries in all continents. Isabel also develops R&D activities with commercial companies in the areas of aggregate characterization, diagnosis of concrete deterioration mechanisms by petrographic methods and geologic and geotechnical mapping of rock masses for large dams, reservoirs and tunnels, with about 90 unpublished reports.

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Dr Miguel Ferreira is an expert on deterioration mechanisms of mineral-based building materials; service life design, assessment, durability modelling of reinforced concrete structures; and ageing management systems. He is an active member in the international Technical Groups: RILEM, FIB, and ICIC, as well as the Finnish Concrete Association. Miguel has authored more than 100 peer-reviewed scientific publications. He has also supervised more than 20 MSc theses and co-supervised 1 PhD thesis.

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