

KAMARUDIN AB-MALEK & ALAN D ROBERTS

FROM
PELHAM
TO **PENANG**

NATURAL RUBBER BEARINGS FOR CIVIL ENGINEERING

This book presents a summary of the various scientific and technological studies related to rubber-bonded steel laminate bearings and their engineering use in bridges and buildings. Contributors to this field are members of the scientific staff of the Malaysian Rubber Board (MRB), via its two laboratories of the Rubber Research Institute of Malaysia (RRIM) in Kuala Lumpur and the Tun Abdul Razak Research Centre (TARRC) in the UK. The chapters cover basic facts about rubber and its historical use in civil engineering, with a particular focus on structures that benefit from vibration isolation and earthquake protection. In the Second Penang Bridge High Damping Natural Rubber (HDNR) bearings are used to ensure that the bridge survives against any major earthquakes in its proximity. The book will be of value not only to scientists, technologists and engineers working in research institutes and in the rubber and construction industries, but also to a wider audience.

PELHAM

Bridge

Harzma
12/8/24.



FROM **PELHAM** TO **PENANG**
NATURAL RUBBER BEARINGS DEVELOPMENT
FOR CIVIL ENGINEERING

PUSTAKA PERDANA



1013638

Published by
Malaysian Rubber Board

(A Statutory Agency under
the Ministry of Plantation Industries and Commodities)



633.8



PERDANA
LEADERSHIP
FOUNDATION
YAYASAN
KEPIMPINAN
PERDANA

FROM **PELHAM** TO **PENANG**
NATURAL RUBBER BEARINGS DEVELOPMENT
FOR CIVIL ENGINEERING

by
Kamaruddin Ab Malek and Alan D Roberts



Design & Concept:

ARS Designbuilders Sdn Bhd

National Library of Malaysia

Kamarudin Ab-Malek

From Pelham to Penang: Natural rubber bearings development for civil engineering / Kamarudin Ab-Malek, Alan D. Roberts

ISBN: 978 983 2088 400

1. Seismic rubber bearings 2. Seismic protection 3. Vibration isolation 4. Bridges 5. Earthquake

I. Robert, A.D. II. Malaysian Rubber Board III. Title

Cataloguing-in-Publication Data

© Malaysian Rubber Board, 2013

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system of any nature, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the publisher.

Website: www.lgm.gov.my



CONTENTS

FOREWORD	12	Rubber properties and the design of mounts	45
MESSAGE	14	Albany Court and other buildings	45
PREFACE	16	Other practical examples of vibration isolation	48
1 ENGINEERING PROPERTIES OF NATURAL RUBBER	21	Noise reduction at source	50
Uses of rubber	23	Recent development of Park House	52
Mechanical properties	24	Conclusion	54
Incompressibility	25	References	54
Stress-strain behaviour	25	4 EARTHQUAKE PROTECTION OF STRUCTURES	56
Hardness	26	The need for earthquake resistant buildings	56
Dynamic behaviour	26	Base isolation for earthquake protection	56
Bonding rubber to metal and other materials	28	Characteristics of HDNR seismic bearings	61
Strain concentration factors	28	Implemented base-isolation schemes	57 67
Resistance to environment	28	Examples of other implemented projects	68
Effect of temperature on stiffness	28	USC University Hospital, 1991	68
Glass hardening at low temperatures	30	Buildings with HDNR bearings in Indonesia	70
Low temperature crystallization	30	Buildings on HDNR bearings in China	72
Chemical resistance	30	Retrofit building in Armenia	73
High temperatures	30	Kobe earthquake	75
Oxygen	31	Sabah building	77
Ozone	31	Demonstration building in Algeria	78
Longevity	32	Parand New Township in Iran	80
Conclusion	32	Current earthquake design codes	82
References	32	Ongoing prospects	82
		Conclusion	82
		References	83
2 EARLY APPLICATIONS OF NR IN STRUCTURES	34	5 HOW LONG CAN NR BEARINGS LAST?	86
Bridge bearings	35	Longevity of natural rubber structural bearings:	86
Design of laminated bearings	37	Pelham Bridge	87
Barrages for flood control	38	The investigation	87
Marine engineering	40	Design and original tests	87
Conclusion	42	Bearings removed	88
References	42	Mechanical tests	88
		Chemical analytical tests	90
3 VIBRATION ISOLATIONS	44	Conclusion of Pelham Bridge tests	91
Principles of vibration isolation	44	Pelham Bridge revisited	91
Dynamic stiffness	44	The effect of 42-year immersion in seawater on natural rubber	92
Building mounts	44		

Experimental methods	92
Results	92
Conclusion of sea water immersion	98
References	98

6 BEARINGS FOR OFFSHORE APPLICATIONS 100

Shock cells	100
Design considerations	101
Platform installation	104
Conclusion	107
References	107

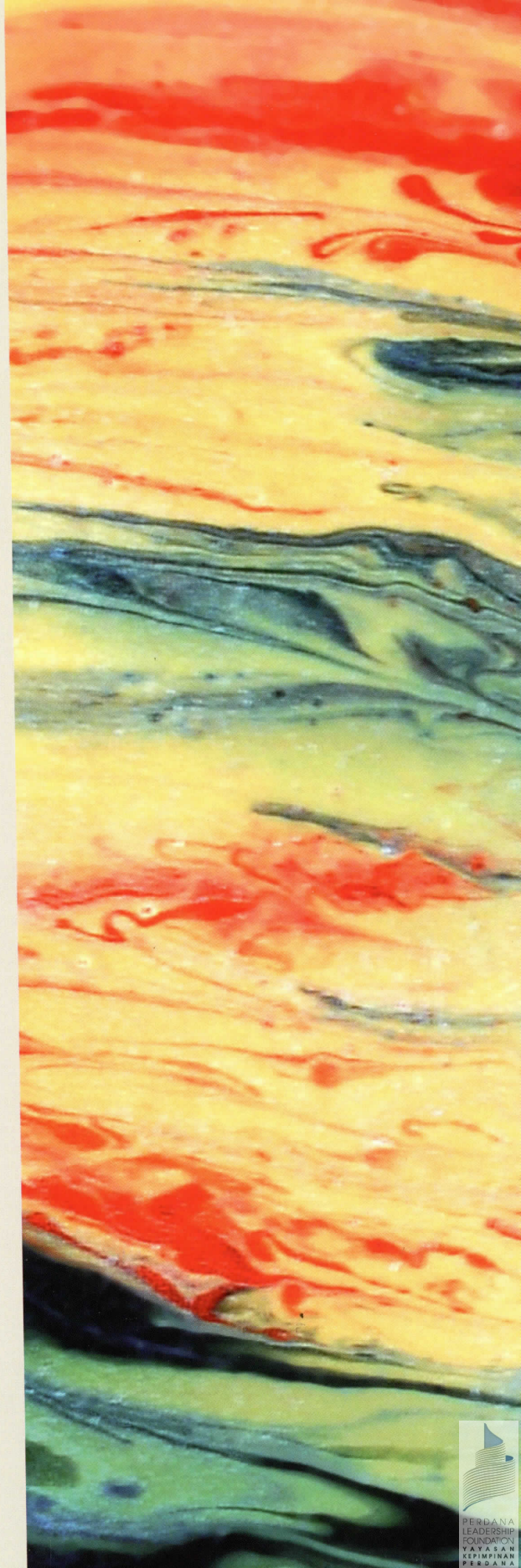
7 HIGH DAMPING NR BEARINGS FOR THE SECOND PENANG BRIDGE 110

The bridge structure	112
Seismic analysis	116
Characteristics of the isolation system	117
Design requirements of the HDNR bearings	117
HDNR bearing design for the sea section	118
Accommodating shrink and creep of the deck	120
Bearing dimensions	125
Land section HDNR bearings	125
HDNR bearing tests	126
Materials tests	128
Production inspection	128
Conclusion	128
References	129

8 THE FUTURE 132

INDEX

134



FOREWORD

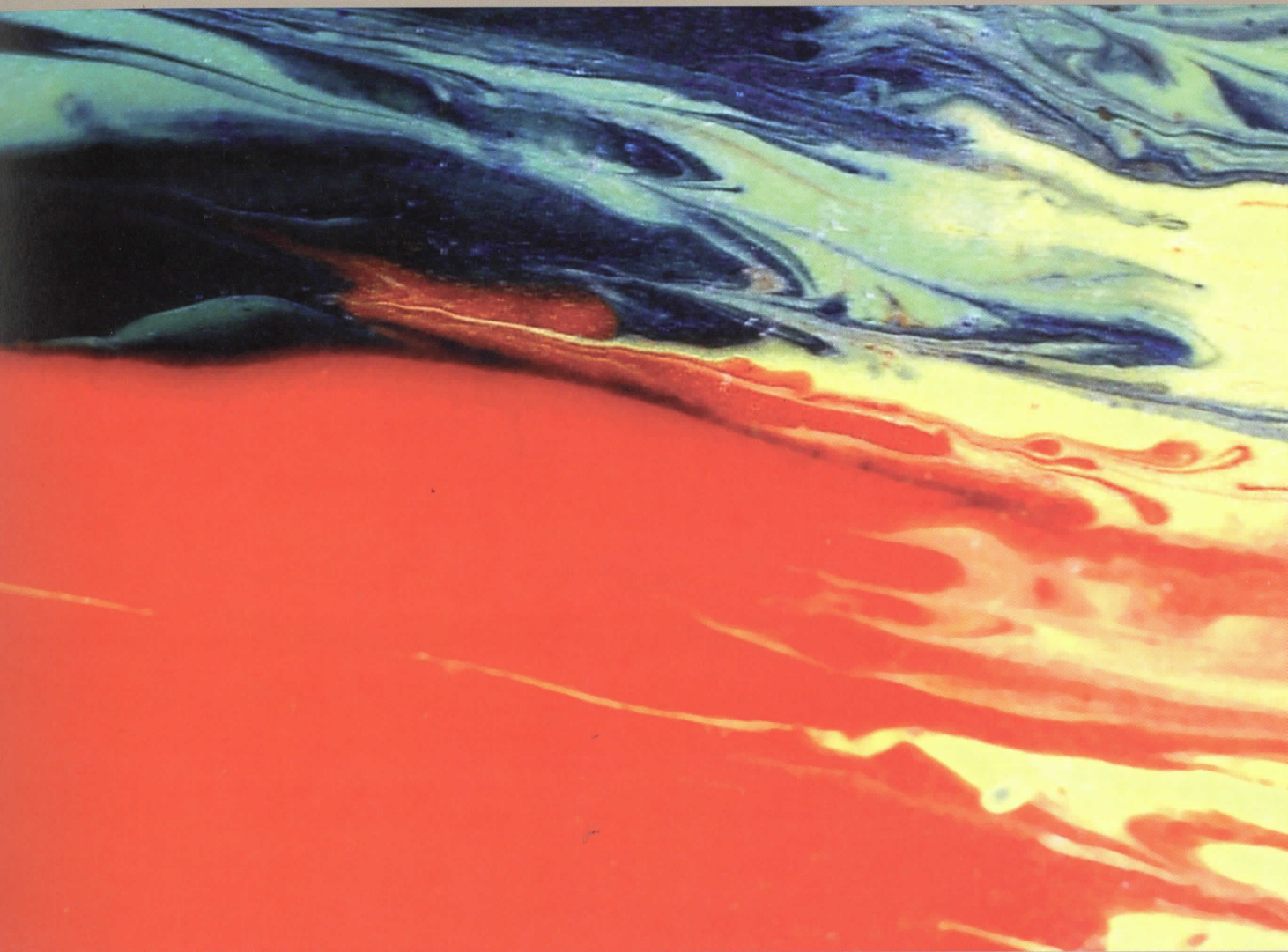
This book has been produced to mark the opening of the Second Penang Bridge spanning from the Malaysian mainland at Batu Kawan westward to Batu Maung on Penang Island. Being 24km long it is the world's largest structure on High Damping Natural Rubber bearings (HDNR). The use of such bearings will ensure that it is fully protected in the event of any major earthquake in the area. The HDNR bearings are a product of Malaysian research and manufacture, an indicator of advancing technological prowess.

Construction of the Second Penang Bridge began in 2008 and was completed five years later on budget and on time. It serves a rapidly growing industrial development and thriving communities on either side.

This book traces the scientific and technological pedigree of the bridge's bearings going back 55 years to the inception of rubber-steel laminated support bearings for bridges. The description given outlines how problems, both technical and conceptual, were overcome to arrive at a new type of natural rubber bearing suitable for the earthquake protection of structures. Such a bearing has been referred to as 'semi-intelligent'. This book relates our experience of a long journey from simple rubber supports for a railway viaduct a hundred years ago to sophisticated rubber-steel laminates for the first seismic protected Malaysian bridge.

The Second Penang Bridge is scheduled to be opened in late 2013. With the construction of this bridge it is anticipated that more bridges in the world's earthquake-prone countries will use this technology.

DATUK DR SALMIAH AHMAD
Chairman of Tun Abdul Razak Research Centre,
and Director General of the Malaysian Rubber Board



Latex Painting by Ahmad Suhaimi Nordin of MRB

MESSAGE

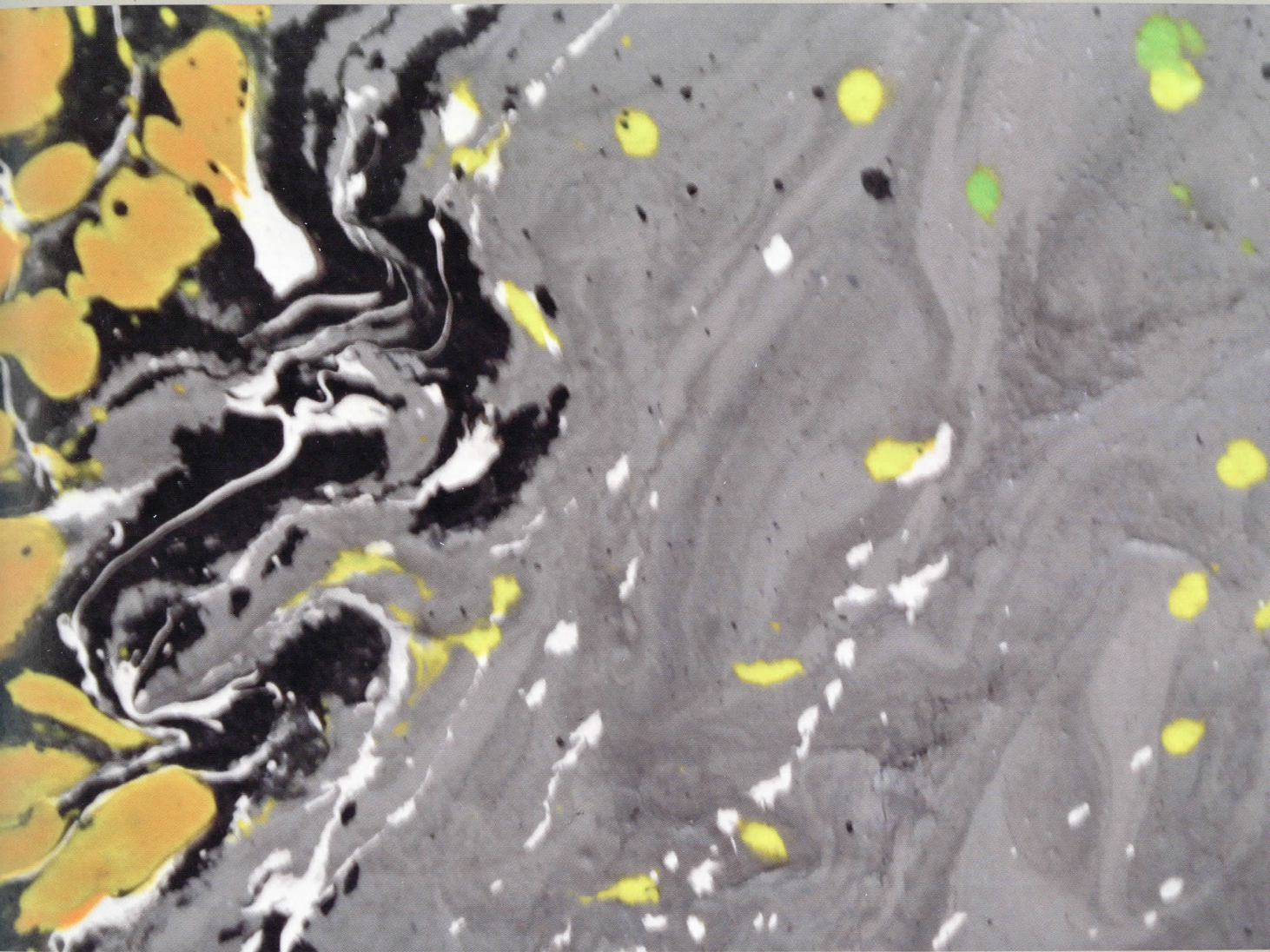
Jambatan Kedua Sdn Bhd is proud to present to the world the longest bridge that is protected against major far field earthquakes using a seismic isolation technique. The High Damping Natural Rubber (HDNR) seismic bearings used in the project are the result of pioneering research at the Malaysian Rubber Board's Tun Abdul Razak Research Centre (TARRC) in Hertford, UK. The HDNR bearings were designed by TARRC and their manufacture and testing was carried out at the Doshin Rubber factory in Klang under the supervision of the Rubber Technology Centre (RTC), the Malaysian Rubber Board's research centre in Sungai Buloh, Malaysia. The design of the bearings and their quality control procedures comply with the European seismic standard EN 1998 Eurocode 8.

The Government of Malaysia has recognised that the construction of the Second Penang Bridge forms an essential part of an infrastructure programme required for the continuous economic and social development of the northern part of mainland Malaysia.

During the course of the project close collaboration between the Malaysian structural engineers and the Malaysian Rubber Board (MRB) research staff provided an opportunity for transfer of base isolation technology, so that Malaysian bridge engineers can offer this expertise to other seismic areas of the world.

I am therefore delighted to offer my support for the publication of this book aimed at raising the awareness of the public especially in Malaysia to this novel technique developed at Malaysia's Tun Abdul Razak Research Centre in the United Kingdom.

DATUK IR DR. ISMAIL MOHAMED TAIB
*Managing Director of Jambatan Kedua Sdn. Bhd,
Bukit Damansara, 50490 Kuala Lumpur*



Latex Painting by Ahmad Suhaime Nordin of MRB



Second Penang Bridge, Malaysia (Courtesy of JKSB)

PREFACE

This book, written to mark the opening of the Second Penang Bridge, describes the various scientific and technological studies related to rubber-bonded steel laminate bearings and their engineering use in bridges and buildings that have been carried out over the last fifty years by the Malaysian Rubber Board (MRB), via its two laboratories of the Rubber Research Institute of Malaysia (RRIM) in Kuala Lumpur and the Tun Abdul Razak Research Centre (TARRC) in the UK. Contributors to such sustained effort have been members of the scientific staff of the two institutes. The chapters cover basic facts about rubber and its historical use in civil engineering, with a particular focus on structures that benefit from vibration isolation and earthquake protection.

The elastic properties of rubber make it ideal as a 'spring' in particular components such as suspension devices for ground vehicles and noise isolators in buildings. Its initial use in bridges was to allow expansion and contraction of the decking with changes in ambient temperature without imposing large horizontal forces on the piers. In the foundations of buildings the rubber-steel laminate spring was introduced to isolate the building from ground borne vibrations in metropolitan city centres.

Rubber is classified as a viscoelastic material, meaning it has elastic and damping properties to control motion. By special compounding, the damping properties of rubber can be increased and this finds particular use in protecting structures from horizontal ground movement as experienced in earthquakes. In the Second Penang Bridge High Damping Natural Rubber (HDNR) bearings are used both to accommodate thermal expansion of the deck and to protect the bridge against earthquake tremors.

The multi-disciplinary approach most necessary to understand rubber properties has been clearly facilitated by the philosophy of the two institutes. An example has been the co-ordinated application of physics, engineering and dry rubber compounding to find a way of producing HDNR bearings and related accessories for the Second Penang Bridge. This bringing together of a range of resources to bear upon conceiving the best possible bearing for the bridge has resulted in a unique design fit for the 21st Century.

The authors owe much to the board members of the Malaysian Rubber Board for their encouragement and advice. We thank members of staff of the laboratories for countless exchanges of ideas and support. In particular, we thank Kevin P Jones for preparing the Index, Hamid R Ahmadi, Keith N G Fuller and Judith K Picken for their helpful suggestions and proof reading. We are grateful to Fauziah Ab Rahman and Ahmad Suhaimi Nordin for helping in the publishing process.

Brickendonbury
July 2013

KAM / ADR



MALAYSIAN RUBBER BOARD

18th Floor, Bangunan Getah Asli (Menara), 148, Jalan Ampang,
50450 Kuala Lumpur, Malaysia. Tel: 603-9206 2000 Fax: 603-2163 4492
www.lgm.gov.my

ISBN 978-983-2066-40-0



PERDANA
LEADERSHIP
FOUNDATION
YAYASAN
KEPERMUKH
PIRAGANA