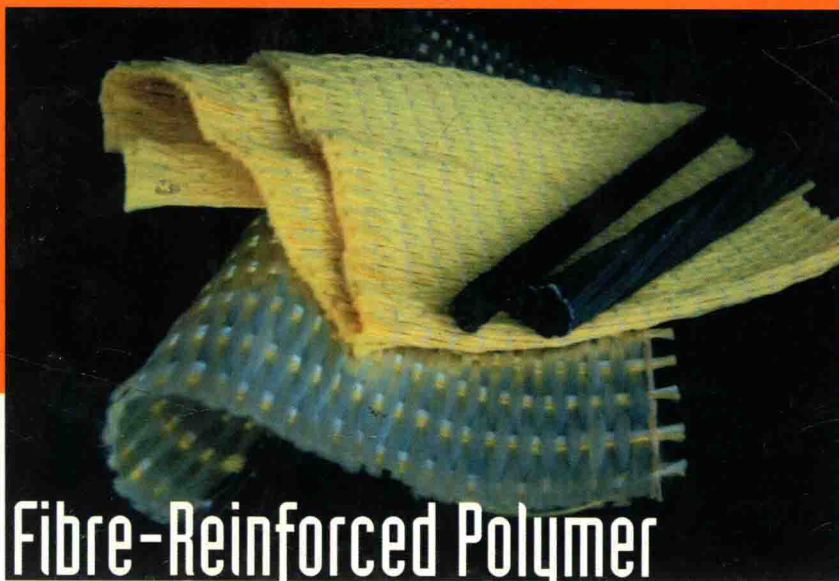


Edited by **Kiang Hwee TAN**



# **Fibre-Reinforced Polymer Reinforcement for Concrete Structures**

**VOLUME 1**

**Proceedings of the  
Sixth International  
Symposium on FRP  
Reinforcement for  
Concrete Structures  
(FRPRCS-6)**



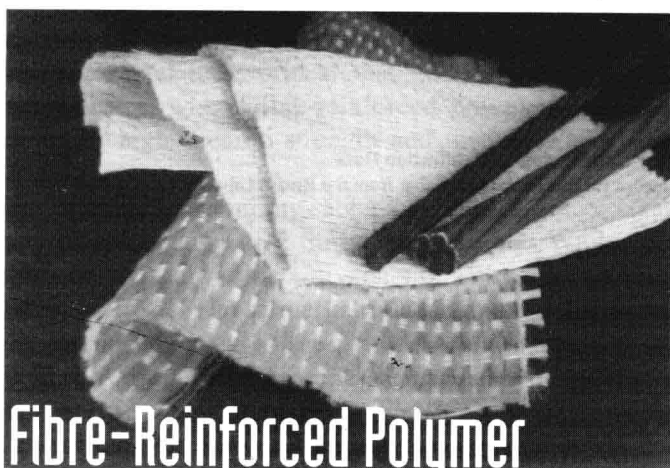
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**Fibre-Reinforced Polymer**

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**Proceedings of the Sixth International Symposium on FRP Reinforcement for  
Concrete Structures (FRPRCS-6)**

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## Preface

Research on the application of fibre-reinforced polymer (FRP) as reinforcement for concrete structures appeared in as early as the 1960s. However, it was not until the late 1980s that such research has escalated, leading to field applications. The interest in non-metallic reinforcement was fuelled by the corrosion problem associated with steel reinforcement that surfaced around the world at that time, and the downturn of the aerospace industry, where fibre-reinforced polymers have been widely used due to its high specific strength and modulus, and other superior characteristics.

I was fortunate to spend my sabbatical with Professor Naaman at the University of Michigan, USA, during the Fall and Winter of 1991 and with Professor Okamura at the University of Tokyo, Japan, during Spring and Summer of 1992. The former introduced to me this new material that has since fascinated many in the research community and construction industry. In Tokyo, in particular, I was overwhelmed by the mountains of research that were embarked by universities, public institutions and private companies on the development and application of FRP rods as reinforcement for concrete structures. There were round bars, flat bars, square bars, braided bars, sanded bars, strands, grids and links, and even three-dimensional reinforcement. Several applications in footbridges, foundation beams, tunnel linings, and floating structures suddenly mushroomed all over Japan and the rest of the world. That probably constituted the first era in the application of FRP reinforcement in concrete structures.

The FRPRCS Symposia Series was initiated in 1993, and subsequently held every two years in the continents of America, Europe and Asia, on a rotational basis. The previous symposia were held in Vancouver, Canada (1993), Ghent, Belgium (1995), Sapporo, Japan (1997), Baltimore, USA (1999), and Cambridge, UK (2001). This year marks the 10th anniversary of the FRPRCS Symposia Series, and the Department of Civil Engineering at the National University of Singapore is honored to host the 6th International Symposium on FRP Reinforcement for Concrete Structures (FRPRCS-6) in Singapore.

The planning and preparation works for FRPRCS-6 in effect began almost six years ago in 1997 when I was asked in Sapporo, to be the second Asian host for the FRPRCS International Symposium. At that time, there was still little awareness of the material known as FRP reinforcement in Asia outside Japan, and if any, the interests were centered mainly on externally bonded FRP systems rather than FRP reinforcing rods. The Kobe earthquake in 1995 has brought about rapidly increasing interests in the use of FRP systems in structural rehabilitation, and that marked the beginning of the second era in FRP applications in concrete structures.

To promote awareness and interests in the development and application of FRP reinforcement in Singapore and the region, the Fibre-Reinforced Society (Singapore) was formed in September 2002 and has since been a co-organizer of this Symposium.

The FRPRCS-6 International Symposium will signify the beginning of the third era, in which one could witness global interests in FRP reinforcement, as well as the use of FRP reinforcements as structural shapes, and in masonry and steel structures. This set of proceedings contains a total of 140 papers from 26 countries, in two volumes. Each technical paper had been reviewed and selected for presentation by at least two members of the International Scientific Committee, to whom I would like to express my gratitude.

Volume 1 of the proceedings contains four invited keynote papers and 63 technical papers dealing with: (i) FRP Materials and Properties; (ii) Bond Behaviour; (iii) Externally Bonded Reinforcement (EBR) for Flexure, Shear and Confinement; and (iv) FRP Structural Shapes. The topics covered in Volume 2 are: (v) Durability and Maintenance; (vi) Sustained and Fatigue Loads; (vii) Prestressed FRP Reinforcement and Tendons; (viii) Structural Strengthening; (ix) Applications in Masonry and Steel Structures; (x) Field Applications and Case Studies; and (xi) Codes and Standards. Seventy-three papers are included in Volume 2.

The FRPRCS-6 International Symposium also witnessed the formation of the International Steering Committee, which comprises the chairmen of the current and previous FRPRCS Symposia. The main purpose of this Committee is to chart the future directions for the Symposia Series. It has appointed a three-man taskforce to determine the Best Paper (Research), Best Paper (Application) and Honorable Mention Awards, which were first introduced at FRPRCS-6. The three gentlemen in the taskforce were Professor C.W. Dolan from USA, Professor F.S.

Rostásy from Germany, and Professor H. Okamura from Japan. All of them are well known in the areas of FRP reinforcement and structural concrete.

The organization of the Symposium would not have been possible without the generous contributions from the sponsors, who are degussa-MBT (S) Pte Ltd, Fyfe Asia Pte Ltd, Mapei Far East Pte Ltd, Sika (S) Pte Ltd, Lee Foundation (Singapore) and Defence Science & Technology Agency. I would also like to express my sincere thanks to the American Concrete Institute, USA, Institution of Engineers, Singapore, Japan Concrete Institute, Japan, and The Concrete Society, UK, for supporting the event.

Last, but not least, I would like to acknowledge the help of my colleagues, in particular, Balendra, Mansur and Maalej, and the Secretariat, comprising Christine, Siti and Sarimah, who have devoted many hours in getting the Symposium organized.

*Kiang Hwee Tan*

Singapore  
July 2003

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