FRP FOR CONSTRUCTION IN JAPAN

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SUMMARY

This paper briefly introduces the current situation of FRP related materials, FRP reinforcement for concrete (and steel) structures and FRP shape, in Japan. For FRP reinforcement various statistical data of practical applications and related codes and standard testing methods are shown. For FRP shape, which is not much used in Japan, the most recent research and practical applications are briefly introduced. At the end some new directions for enhancement of FRP usage as construction material are presented.

Keywords*: FRP reinforcement; FRP shape; practical application; code; standard test method.*

INTRODUCTION

Fiber related construction materials are FRP reinforcement (or continuous fiber reinforcement) for concrete and steel structures, FRP shapes and concrete reinforced with short fiber (or fiber reinforced concrete). Types of fiber are carbon, glass, aramid, and other organic fibers such as polyacetal fiber (PAF) and polyester fiber such as Polyethylene Terephthalate (PET).

In this paper an overview on the present situation on FRP reinforcement and FRP shape and their standards/codes is presented.

FRP REINFORCEMENT

Introduction

Japan has been a leading country in terms of the number of practical applications and the amount of FRP reinforcement (or continuous fiber reinforcement) used for concrete. Since

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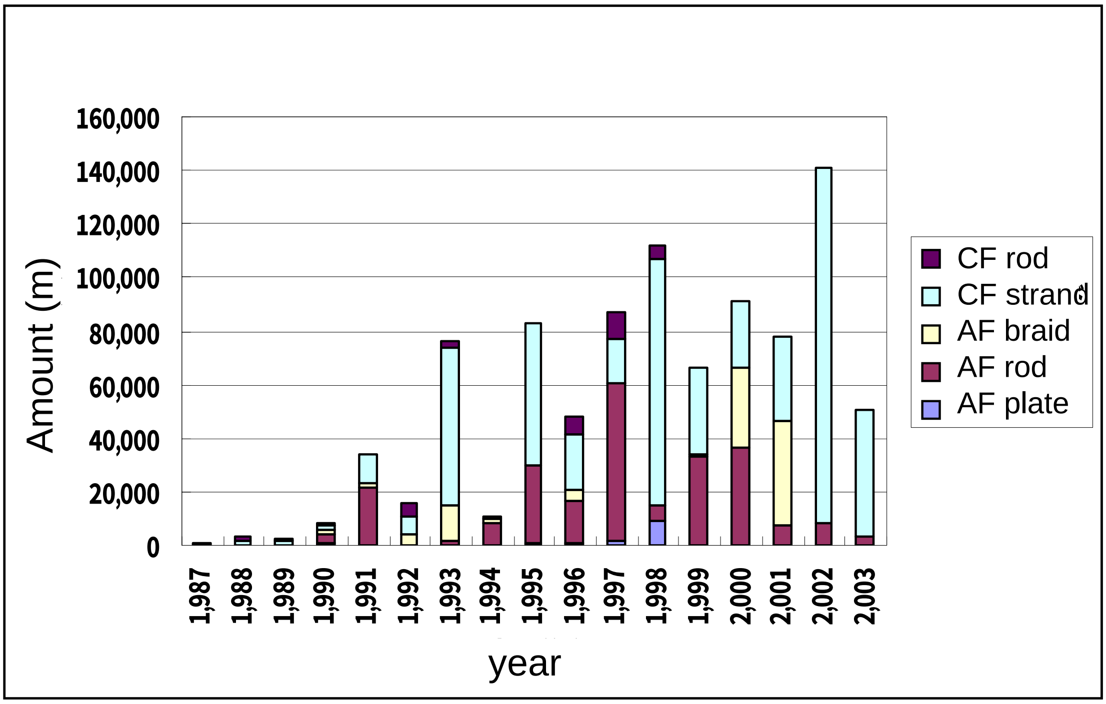
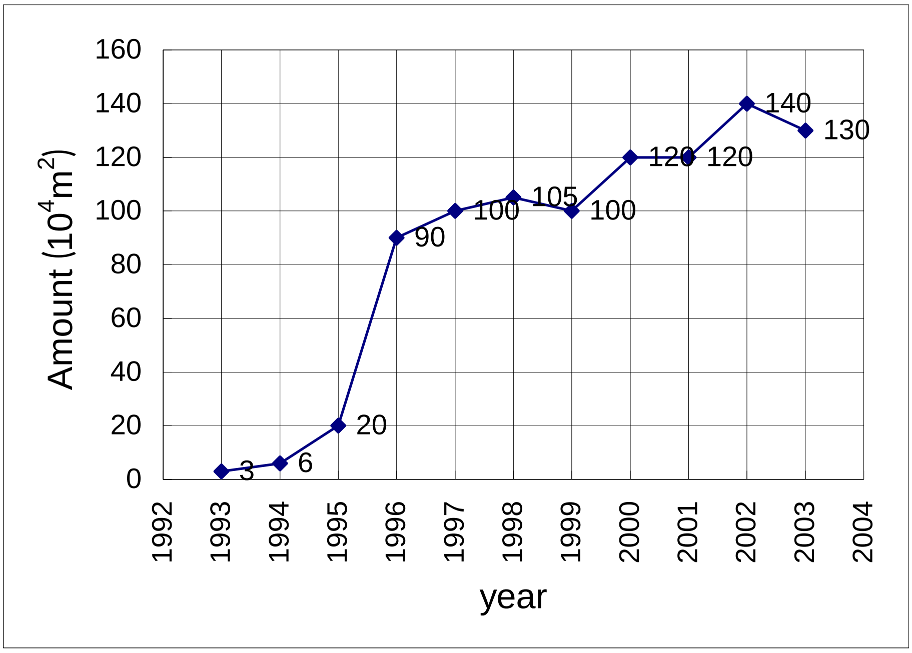
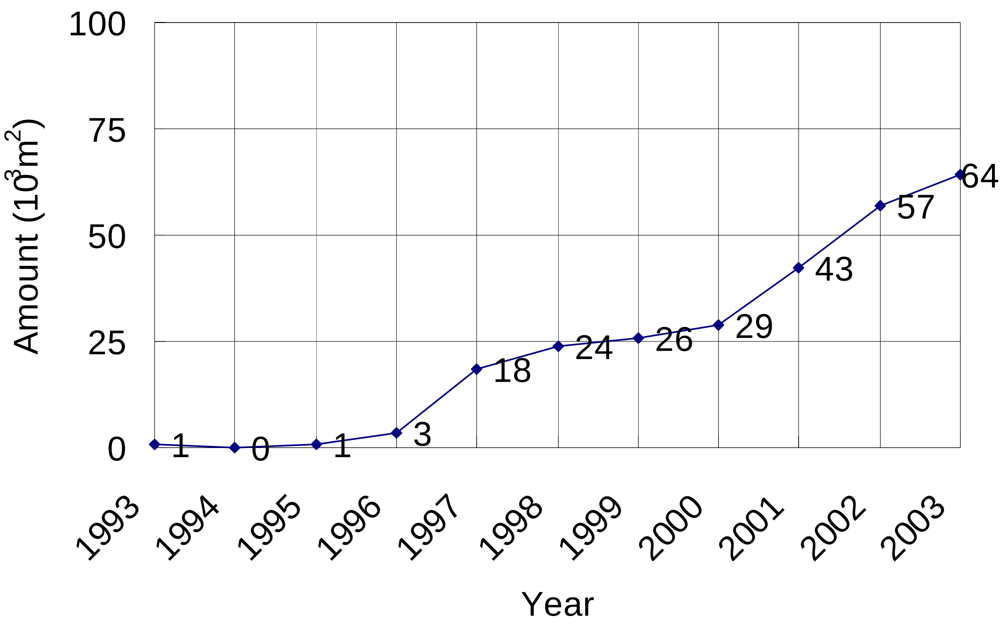
the late 80's the application of FRP reinforcement for concrete has been steadily increasing. Especially after the late 90's the FRP sheet (or continuous fiber sheet) has been applied in many cases for seismic retrofitting, upgrading and durability retrofitting. The Great Hanshin Earthquake is the driving force for seismic retrofitting, while the retrofitting for durability increases significantly due to rising cases of falling concrete pieces from existing structures which threaten human and traffic safety. Figure 1 shows the statistics for the application of FRP reinforcement in Japan.



(a) FRP Reinforcement (excluding grid)
Data source: ACC Club



(b) Carbon fiber sheet
Data source: CFRRRA



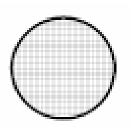
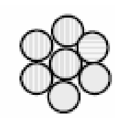
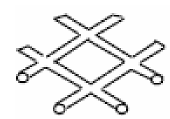
(c) Aramid fiber sheet
Data source: ARSA

Figure 1 Amount of FRP reinforcement used in Japan

FRP Reinforcement – Bar and Grid

In Japan various types of FRP reinforcement are available at present. Types of configuration are rod (round and rectangular), strand, braid, and grid. Fibers for each type are carbon and aramid (rod), carbon (strand), aramid (braid) and carbon, aramid and glass (grid). Table 1 and Fig. 2 show examples of the FRP reinforcement. Major producers in Japan are Teijin for aramid rod, Tokyo Rope for carbon rod and strand, Nittetsu Composite for carbon strand and rod and carbon, aramid and glass grid, Fibex for aramid rod, and Mitsubishi Chemical for carbon rod.

Table 1 Configuration of FRP reinforcement for concrete in Japan

Type	Rod (round)	Rod (rectangular)	strand	braid	grid
Symbol	R, D	P	S	B	L
Configuration					

The practical application of FRP reinforcement bars for concrete existed since 1987 (see Figs. 1 and 3). The total number of applications is around 180, while the amount of FRP used is around 0.9 million meters. The number of practical applications is steadily decreasing since 1996, however the amount used does not decrease much. Both number of applications and amount used of carbon fiber strand is the most.

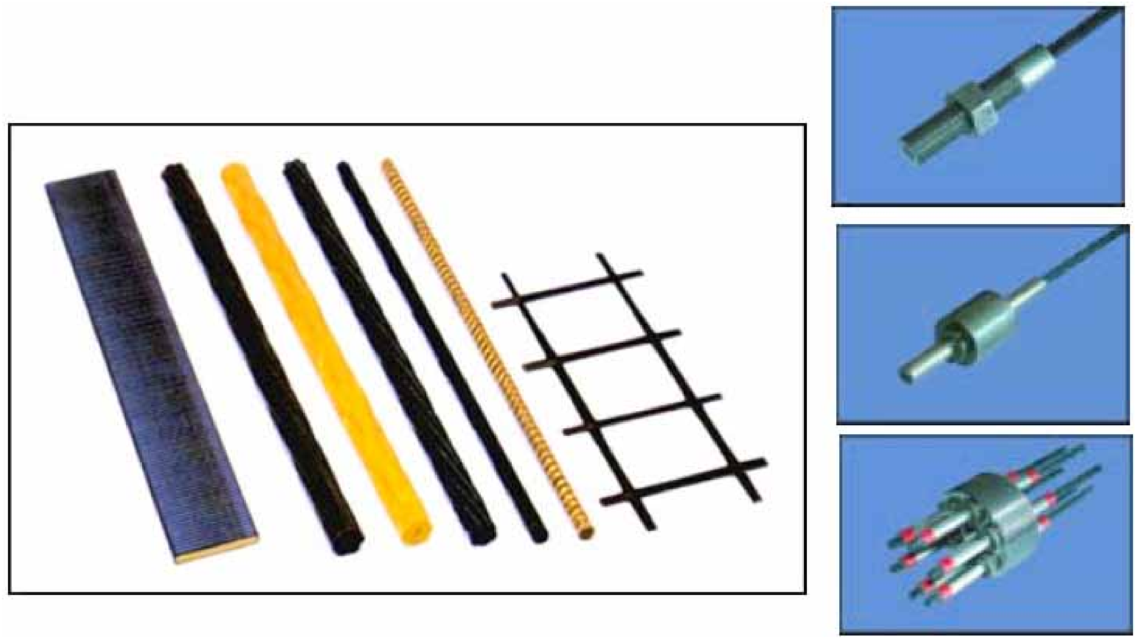


Figure 2 Examples of FRP reinforcement for concrete in Japan

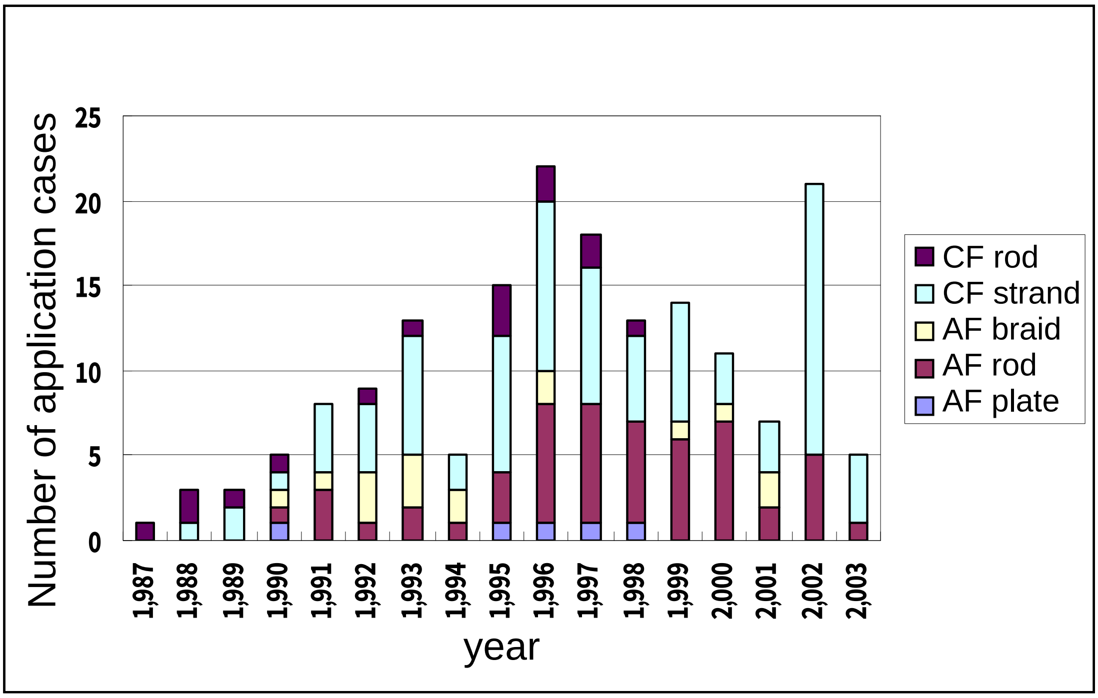


Figure 3 Number of practical applications for FRP reinforcing bars in Japan
Data source: ACC Club

Figure 4 shows the number of applications for different types of structures. At the early time many applications were applied to coastal and water channel structures where highly durable materials are required, however there is almost no application after 2001. In 1993, 2000 and 2001 FRP reinforcement was applied to structures that require non-magnetic characteristics in construction materials. Application to bridges had steadily increased until 1998 but no longer increased after that. Only application to ground anchor has been increasing recently.

The application to bridges is the most, which is 0.35 million meters, followed by that of ground anchor, which is 0.26 million meters.

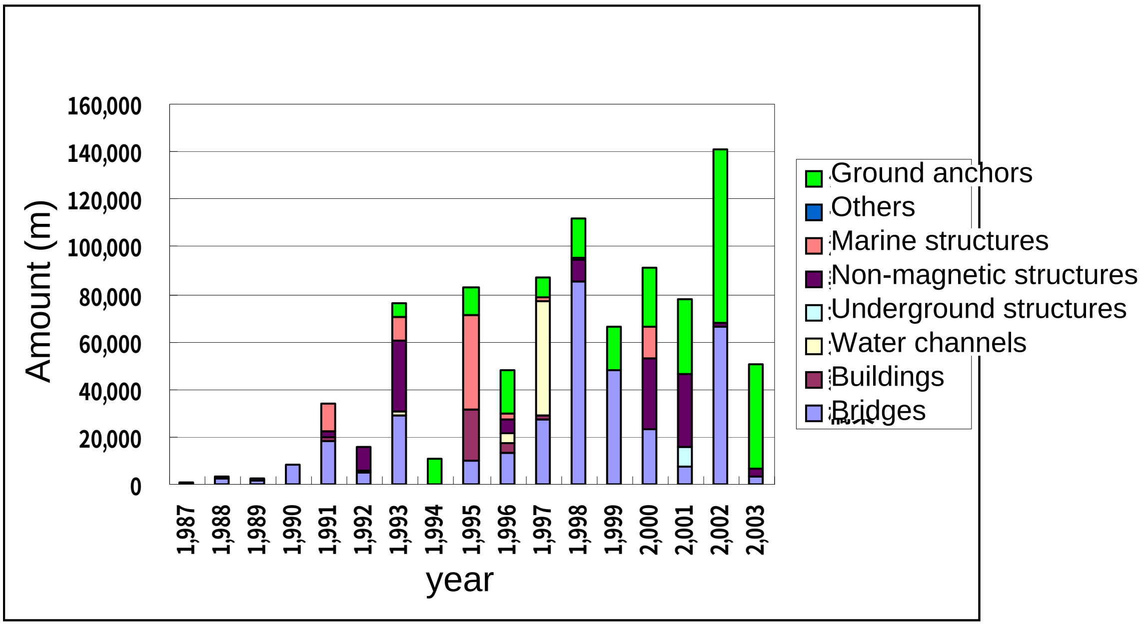
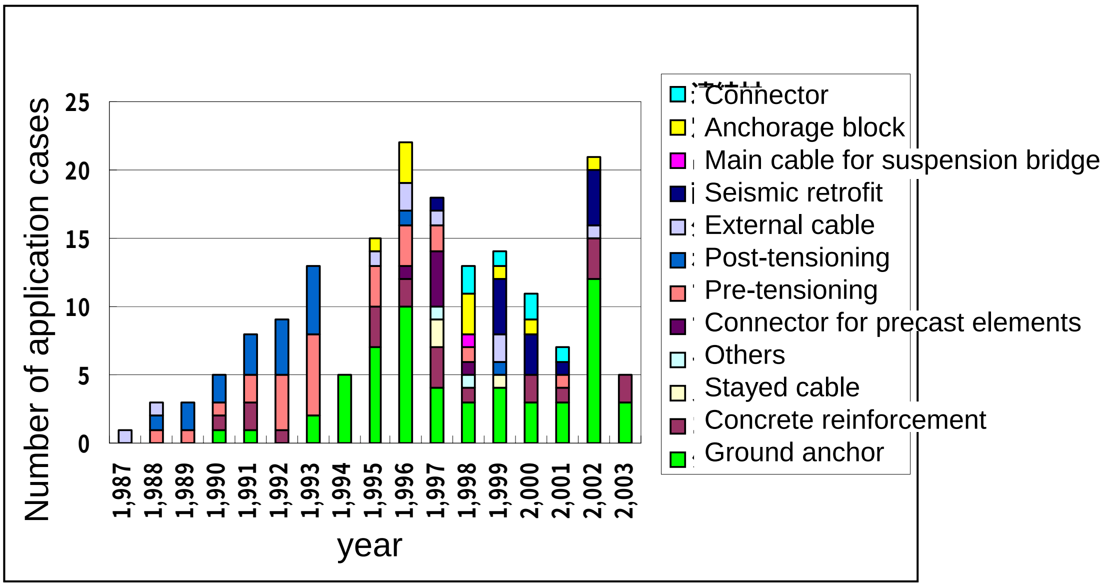
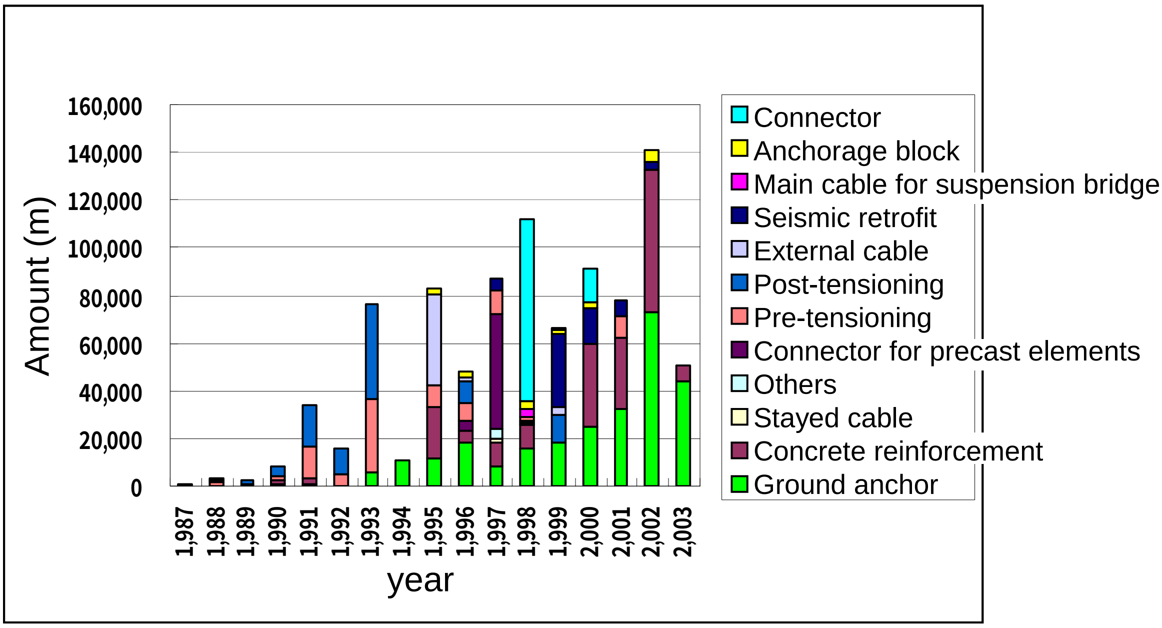


Figure 4 Amount used of FRP reinforcing bars for different type of structures
Data source: ACC Club

The number of applications and the amount used are classified according to application type as shown in Fig. 5. Until 1994 applications to post- and pre-tensioning steadily increased. They are mostly trial cases for pedestrian bridges, beams and slabs for piers, with a few cases of highway bridges. In 2002 carbon fiber strands were applied as loop joint reinforcement at prestressed concrete slab joints, which is categorized as concrete reinforcement. In two instances abroad FRP reinforcement produced in Japan has been applied as cables in bridges.



(a) Number of applications
Data source: ACC Club



(b) Amount used
Data source: ACC Club

Figure 5 FRP reinforcing bars for different application types

A comparison of the amount of different FRP reinforcement types used is shown in Fig. 6. Carbon fiber strand is top with 0.53 million meters, out of which 0.23 million meters is for ground anchor. Aramid rods, whose total amount used is 0.23 million meters, have been used for seismic retrofit, connection for precast elements and ordinary concrete reinforcement. Aramid braids have been used as ordinary concrete reinforcement and the total amount is 0.1 million meters. In the figure the amount of carbon fiber rod is 35 thousand meters, however another 50 thousand meters has been used as reinforcement of concrete walls through which tunnel boring machine went. The reason of this application is the fact that FRP reinforcement can be easily sheared off.

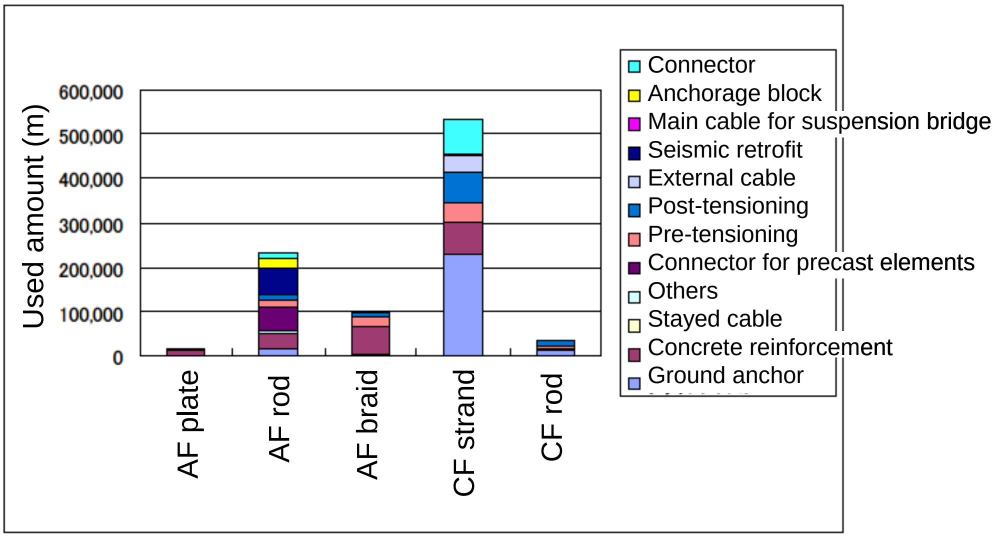


Figure 6 Amount used of different types of FRP reinforcement
Data source: ACC Club

FRP Reinforcement – Sheet

FRP reinforcing bars and grids are usually meant for substitute of steel reinforcement for new structures, while FRP reinforcements in sheet form (or FRP sheets) are usually applied for strengthening or repairing of the existing structures. Fiber types for sheet are carbon, aramid and glass. Sheets with fiber in one direction are used for strengthening, while sheet with fiber in two directions are for repairing to improve/restore durability and to avoid concrete pieces from falling from the structure surface.

There are 3 types of carbon fiber sheet for strengthening: high, medium and low Young's modulus type (230, 390~440 and 540~640 GPa respectively) as shown in Table 2 and 2 types: high and low Young's modulus for aramid fiber sheet (114 and 78.4 GPa respectively). Fracturing strain of aramid fiber sheet is around 4 % which is higher than around 1.5% of carbon fiber sheet. As a result aramid fiber sheet is used for seismic retrofit requiring ductility enhancement.

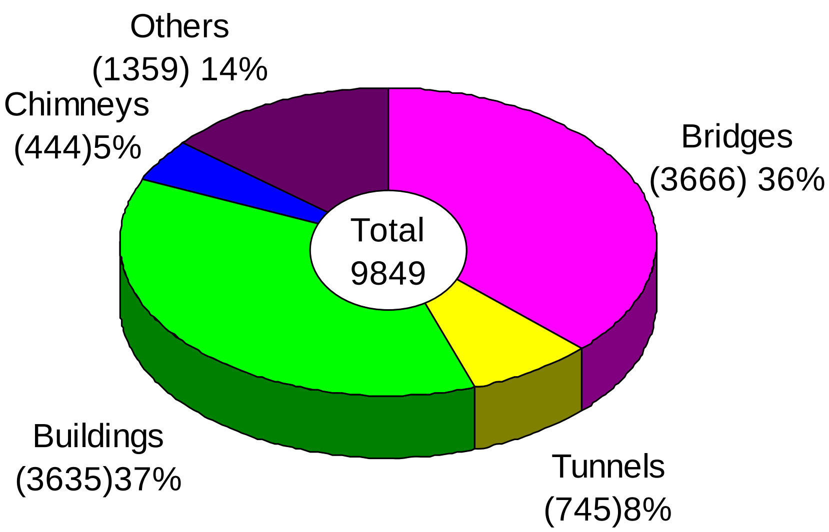
Number of applications for carbon fiber sheet was 9849 at the end of FY2003 (March 2004) and 6.94 million m^2, while 600 and 0.265 million m^2 at the end of FY2003 (March 2004) for aramid fiber sheet. As shown in Fig. 7 (a) and (b), applications to bridge and building are 36 and 37 % for carbon fiber sheet, while 55 and 32 % for aramid fiber sheet. Recently more applications can be seen in the strengthening of beams and slabs and repairing of tunnel lining attributing to a steady increase in the applications of FRP sheet.

The cost of fiber in a 1 m^2 of sheet is ranged from JPY 5,000 to 20,000 depending on fiber amount, while the total construction cost (material and labor) is ranged from JPY 30,000 to over 100,000. When the total construction cost is equivalent to or less than that of steel plate jacketing (strengthening with steel plate), which costs JPY 25,000 to 100,000, and concrete jacketing whose cost is usually less than JPY 60,000, FRP sheet jacketing is likely to be chosen. Construction constraints on space and/or time often make FRP jacketing more economical than steel and concrete jacketing.

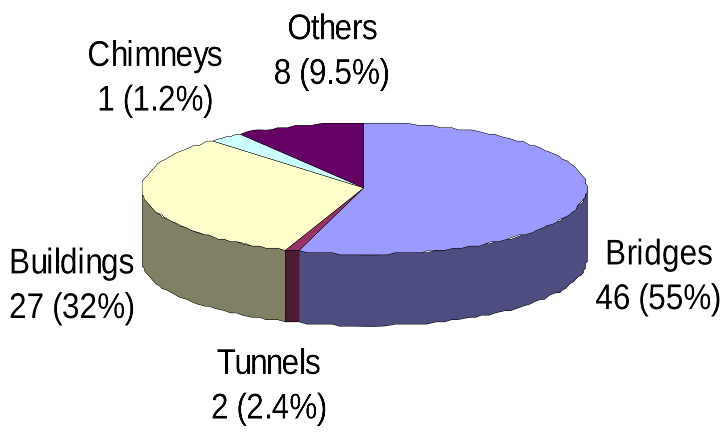
Table 2 Examples of FRP Sheet

Type	Fiber amount g/m2	Design thickness mm	Tensile strength N/mm^2	Young's modulus N/mm^2	Tensile ultimate force kN/m	Tensile stiffness kN/mm
High strength CFRP sheet with unidirectional fiber	200	0.111	3,400	230,000	390	27.2
	300	0.167	3,400	230,000	590	38.4
	200	0.113	2,942	230,000	332	25.9
	300	0.169	2,942	230,000	497	38.9
	400	0.222	3,400	230,000	755	51.1
	450	0.250	3,400	230,000	850	57.5
	600	0.333	3,400	230,000	1,130	76.6
Medium stiffness CFRP sheet with unidirectional fiber	300	0.165	2,900	390,000	478	64.4
	300	0.163	2,400	440,000	391	71.7
High stiffness CFRP sheet with unidirectional fiber	300	0.143	1,900	540,000	271	77.2
	300	0.143	1,900	640,000	271	91.5
CFRP sheet for slab strengthening	340	0.209	2,400	390,000	396	81.5
	380	0.185	2,400	440,000	396	81.5
	270	0.128	1,900	640,000	245	81.9
CFRP sheet with two-directional fiber for repair	200(100)	(0.055)	(2900)	(230,000)	(160)	(12.8)
	300(150)	(0.083)	(2900)	(230000)	(242)	(19.1)
AFRP sheet with unidirectional fiber (aramid 1)	280	0.193	2,060	118,000	390	22.7
	415	0.286	2,060	118,000	590	33.7
	623	0.430	2,060	118,000	880	50.7
	830	0.572	2,060	118,000	1,180	67.5
AFRP sheet with unidirectional fiber (aramid 2)	235	0.169	2,350	78,400	390	13.2
	350	0.252	2,350	78,400	590	19.8
	525	0.378	2,350	78,400	880	29.6
	700	0.504	2,350	78,400	1,180	39.5
AFRP sheet with two-directional fiber (aramid 1)	650(325)	(0.193)	(2,060)	(118,001)	(392)	(22.7)
	870(435)	(0.24)	(2,061)	(118,000)	(490)	(28.3)
AFRP sheet with two-directional fiber (aramid 2)	90(45)	(0.024)	(2,062)	(118,001)	(49)	(2.8)
	105(52.5)	(0.031)	(2,063)	(110,000)	(49)	(3.4)
	175(87.5)	(0.0608)	(2,064)	(90,000)	(98)	(5.4)
	175(87.5)	(0.0608)	(2,065)	(100,000)	(98)	(6.1)
	180(90)	(0.048)	(2,066)	(118,000)	(98)	(5.7)
AFRP sheet with two-directional fiber for repair (aramid 2)	162(81)	(0.058)	(2,350)	(78,400)	(135)	(4.5)
GFRP sheet with uni-directional fiber	300	0.118	1,500	73,000	177	8.6

Note: Table 2 is prepared based on the data from CFRRRA and ARSA.



(a) Carbon fiber sheet (from FY1987 to FY2003)
Data source: CFRRRA



(b) Aramid sheet (from FY1987 to FY2000)
Data source: ARSA

Figure 7 Number of application by types of structures

Codes for FRP reinforcement

There are codes for FRP reinforcement for new concrete structures (Research Committee on Continuous Fiber Reinforcing Materials 1997; Editorial Committee on Concrete Reinforced with Continuous Fiber Reinforcement 1995) and for upgrading of existing concrete structures (Research Committee on Upgrading of Concrete Structures with Use of Continuous Fiber Sheet 2001). The following two codes are briefly introduced:

(1) Recommendation for design and construction of concrete structures using continuous fiber reinforcing materials (Research Committee on Continuous Fiber Reinforcing Materials 1997)

The Recommendation for design and construction of concrete structures using continuous fiber reinforcing materials can be applied to most of the FRP reinforcing bars available in Japan, which are carbon and aramid bars (round/rectangular rods, strands and braids) and carbon, aramid and glass grids. The Recommendation is prepared in accordance with JSCE's Standard Specifications for Concrete Structures and introduces new design formulas, such as those for shear strength of linear members and anchorage length.

At the same time related standards were published by JSCE. They are Quality Specifications for Continuous Fiber Reinforcing Materials, which specify the material properties of FRP reinforcements and the following test methods:

- Test method for tensile properties of continuous fiber reinforcing materials
- Test method for flexural tensile properties of continuous fiber reinforcing materials
- Test method for creep failure of continuous fiber reinforcing materials
- Test method for long-term relaxation of continuous fiber reinforcing materials
- Test method for tensile fatigue of continuous fiber reinforcing materials
- Test method for coefficient of thermal expansion of continuous fiber reinforcing materials by thermo-mechanical analysis
- Test method for performance of anchorages and couplers in prestressed concrete using continuous fiber reinforcing materials
- Test method for alkali resistance of continuous fiber reinforcing materials
- Test method for bond strength of continuous fiber reinforcing materials by pull-out testing
- Test method for shear properties of continuous fiber reinforcing materials by double plane shear

(2) Recommendations for upgrading of concrete structures with use of continuous fiber sheets (Research Committee on Upgrading of Concrete Structures with Use of Continuous Fiber Sheet 2001)

The Recommendations for upgrading of concrete structures with use of continuous fiber sheets are applied to both column and beam retrofit with use of carbon and aramid fiber sheets. Column retrofit means seismic retrofit. The Recommendations were prepared based on Guidelines for Retrofit of Concrete Structures – Draft – (JSCE Working Group on Retrofit Design of Concrete Structures in Specification Revision Committee 2001) in which performance-based concept is accepted.

In the Recommendations verification methods for safety are provided by newly proposed prediction methods of flexural strength, shear strength and ductility. In the flexural strength prediction, interfacial fracture energy concept is applied, while debonding is considered in the shear strength prediction.

The following standard test methods were presented at the same time:

- Test method for tensile properties of continuous fiber sheets
- Test method for overlap splice strength of continuous fiber sheets
- Test method for bond properties of continuous fiber sheets to concrete
- Test method for bond properties of continuous fiber sheets to steel plate
- Test method for direct pull-out strength of continuous fiber sheets with concrete
- Test method for tensile fatigue strength of continuous fiber sheets
- Test method for accelerated artificial exposure of continuous fiber sheets
- Test method for freeze-thaw resistance of continuous fiber sheets
- Test method for water, acid and alkali resistance of continuous fiber sheets

FRP SHAPE

FRP shape manufactured in Japan is around 0.4 million ton a year, a quarter of that the amount manufactured in the USA. In Japan the manufacturing amount of FRP shape does not increase since the beginning of 1990's while in the USA it does to nearly double in the same period. It is expected that the manufacturing of FRP shape in China will grow significantly. Despite the fact that Japan is a leading carbon fiber manufacturing country in the world, carbon FRP shape used in Japan is much less than that in the USA because the primary industry for carbon FRP is aerospace industry there.

A similar situation can be seen in FRP shape in construction industry. The number of practical applications in Japan is much less than in the USA and Europe. There are only two pioneer cases for application to bridge in Japan. In this chapter the state-of-the-art of practical application and research of FRP shape is briefly introduced (Subcommittee on FRP Bridges, Committee of Structural Engineering 2004).

Research

FRP slabs composing GFRP rectangular pipes filled by mortar were analyzed both experimentally and numerically. The experimental approach included fatigue test with traveling axel load. It was observed that the filling mortar increased the ultimate load significantly.

FRP composite slabs consisting of concrete and GFRP panel with FRP stiffener (see Fig. 8) were tested statically and dynamically with traveling axel load. The tested parameter included concrete-FRP panel interface bonding condition. The best bonding was obtained with sand spray treatment for FRP panel.

Boxed-sectioned prestressed concrete girder bridge with GFRP web panel was proposed (see Fig. 9). Recently prestressed concrete girder bridge with steel corrugated web plate is often applied due to the advantage of lightness. Similar concept was found in this FRP web panel. Experiment showed that the proposed new type of bridge possesses appropriate structural performances including ultimate load carrying capacity if appropriate connection between FRP panels and between FRP panel and concrete.

A prototype of **cable stayed pedestrian FRP bridge** was constructed. The spans were 4.5, 11.0 and 4.5 m. Cables and anchorages were CFRP, while girders, decks and pylons were GFRP. Test for disassembling and re-assembling was conducted showing that the re-assembling could be done in a half day.

A **FRP truss highway bridge** was constructed for testing purpose. This bridge spanning 8.0 m was a proto type for a real size of 40 m span, which is used for emergency/temporary restoration purpose. All the truss components were GFRP rectangular pipes. Tests for installation at site and vibration after installation were conducted.

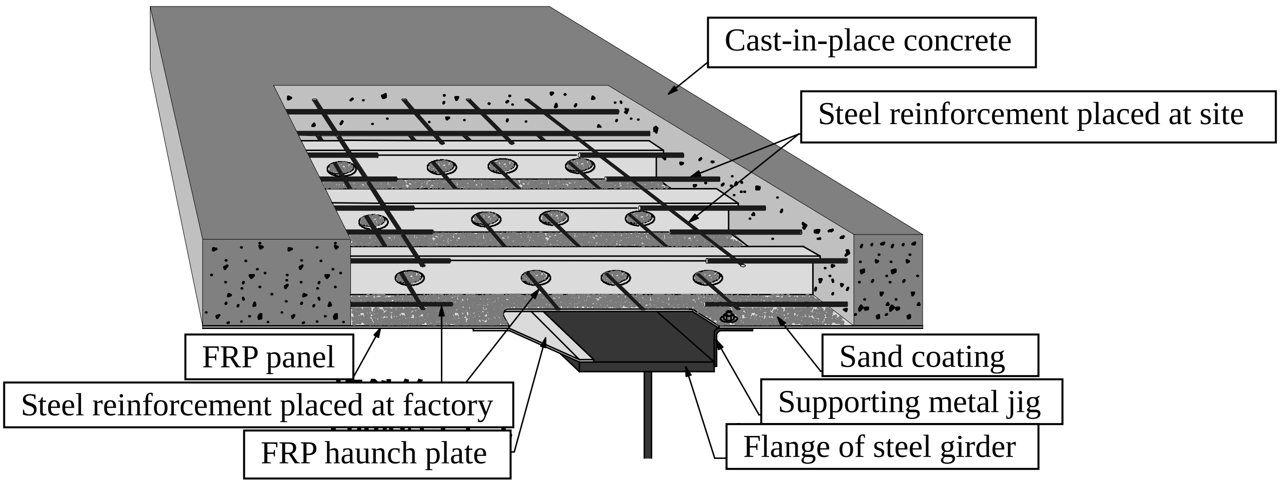


Figure 8 FRP composite slabs consisting of concrete and GFRP panel with FRP stiffener

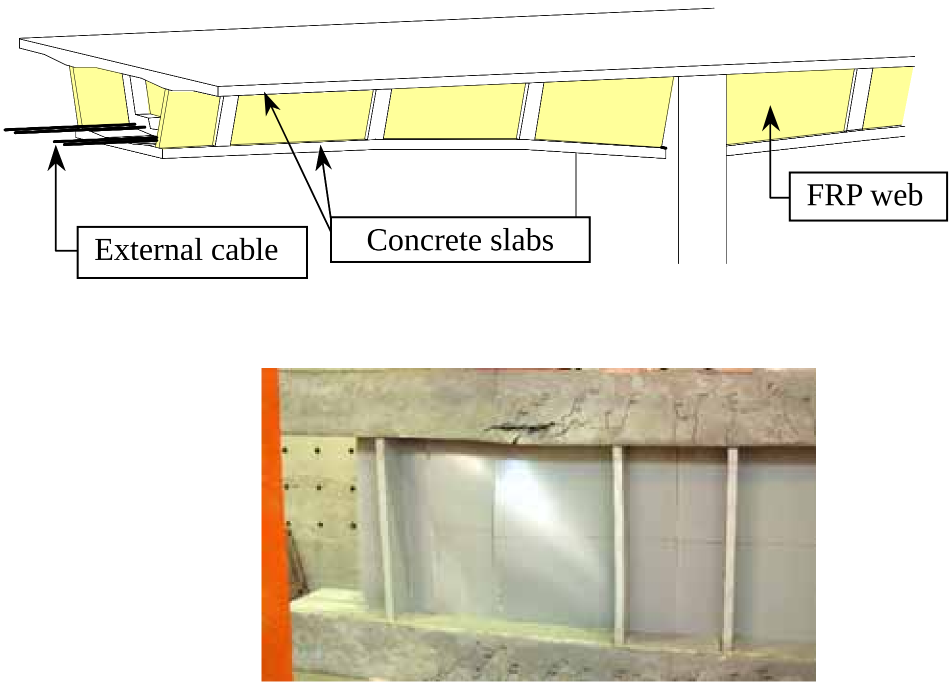


Figure 9 Boxed-sectioned prestressed concrete girder bridge with GFRP web panel

Practical Application

A **FRP pedestrian bridge with two continuous spans** was constructed in Okinawa, Japan in 2000 (see Fig. 10). This is a girder bridge with span lengths of 19.7 and 17.2m. The reason for FRP to be chosen was corrosive environment due to salt attack. All the structural elements were made of GFRP. Tests for joint between FRP elements and for vibration after the completion were conducted.

Strengthening method by adding GFRP beams of existing reinforced concrete bridge deck was proposed. In this strengthening method an additional GFRP beam in the direction parallel to main girders was applied to support the reinforced concrete deck. The GFRP beam was supported by another GFRP beams underneath and adjacent to the existing steel transverse beams. Applicability of the strengthening method was verified by static and fatigue tests and FEM analysis.

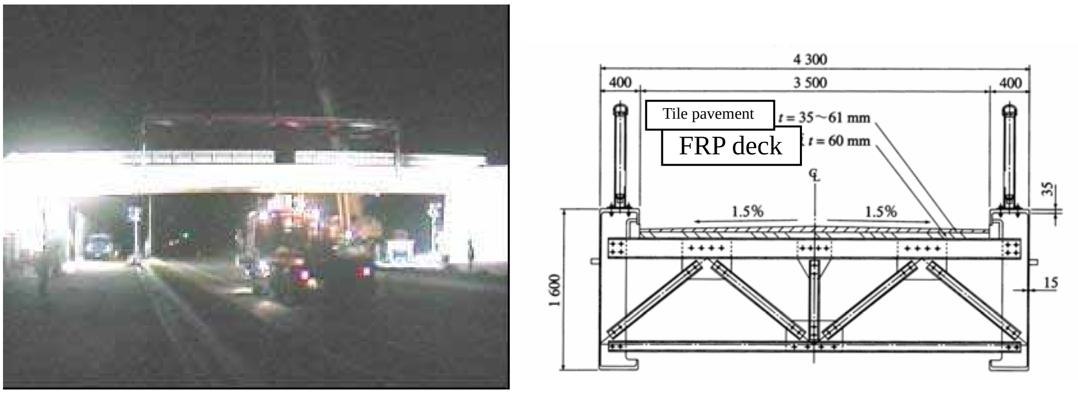


Figure 10 FRP pedestrian bridge with two continuous spans

CONCLUDING REMARKS

FRP related materials, FRP reinforcement for concrete (and steel) structures and FRP shape, in construction in Japan are briefly introduced showing the statistics and related codes. FRP reinforcement in Japan is leading the rest of the world in terms of application and available technology, however FRP shape in Japan is far behind those in the USA and Europe. Overall situation for FRP in construction in Japan does not look so bright at present. Practical examples can be seen in structures under harsh environment and with strict constraints of construction time and/or space.

New directions for enhance FRP market in construction can be seen recently in Japan. One of them is an introduction of life cycle cost (LCC) assessment. Once reliable enough methods for assessing LCC, FRP whose material cost is high but durable can see a brighter future. A recent trial calculation for prestressed concrete girder bridge along sea coast shows that the initial cost of bridge with FRP internal reinforcement is 1.6 times as high as that of with only steel reinforcement but that the life cycle cost of the former is less than a half of that of the latter (ACC Club 2002). Another example is a usage of less expensive fibers which generally have less strength/stiffness but higher fracturing strain (see Fig. 11).

Strength/stiffness can be compensated by providing more amount, however low fracturing strain, which is a weak point of typical fibers such as carbon, aramid and glass, cannot be substituted by any. As examples of such fiber, polyacetal fiber (PAF) and polyester fiber such as Polyethylene Terephthalate (PET) show good performance to enhance ductility of concrete members (see Fig. 12). For the application of these inexpensive fibers a new concept for structural design is necessary.

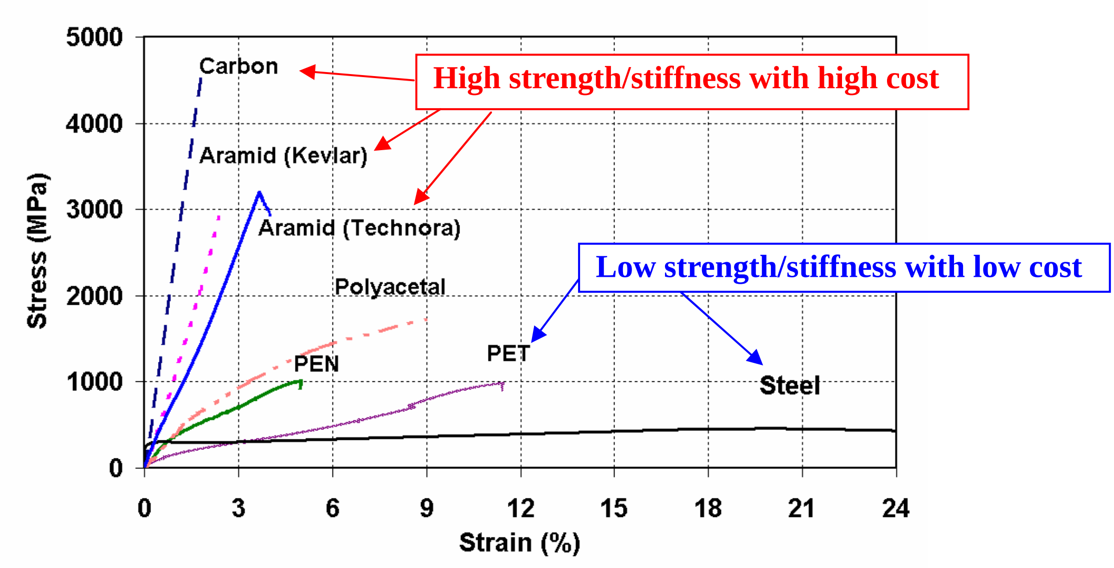


Figure 11 Strength/stiffness and fracturing strain relationship

(a) Column retrofitted with PAF sheet

(b) Column retrofitted with PET sheet

Figure 12 Ductility enhancement by fiber sheet with a high fracturing strain

ACKNOWLEDGEMENTS

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